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Discussion at New York, Feb. 28, 1900.

[See page 1, January issue.]

Mr. Frank J. Sprague:—Mr. President and gentlemen, I have been asked to open this discussion, and I have been spending a part of the afternoon looking at a time-table. I have listened with interest to Mr. Boynton's paper, giving the principal results of his experience on the New York and New Haven road. If I have any criticisms to make of it as a paper, it is that it does not treat of the subject on quite as broad lines as I would liked to have seen. It is more a record of what has been creditably done, with interesting results, in connection with work of the New York and New Haven Railroad, inaugurated at a time when there was a good deal of cynicism expressed. I will take the liberty, if I may, of going back to a review of this subject, and reading from lines written some five years ago, and then make reference to some projects which are now in hand. I think, possibly, I might suggest a title for Mr. Boynton's paper, something like this: "Shall electricity be used on steam railways, and, if so, how far and under what conditions?"

In the paper referred to I stated: "Electrical development will go on until the trolley system is almost as common as the turnpike. It will establish lines of communication which have not hitherto existed; it will build up new territory; it will act as a feeder to great trunk-line systems, both for passenger and certain classes of freight work; and it will largely encroach upon special fields now occupied by the trunk lines.

"But, when we depart from this class of service and take up what is essentially a trunk-line system, there are many questions to be considered, and not alone those of the local and express service, but also a most important one, which is rarely considered when electric railways are talked of. I refer to the trunk-line freight service—that is, the transportation of goods in great bulk over long distances. One must remember that trunk lines, as they now exist, have been built up by a slow process, and that no very serious change from their existing conditions can be made, considered from the commercial standpoint, except after grave deliberation and at very great expense. Unless passengers and goods can be moved over a system with increased benefit to a community, or at a reduced cost, or with a commensurate return on capital invested, an electric will not replace a steam system. Of course, in these remarks I ignore specific problems, such as the utilization of a storage battery and motor in place of a locomotive, or of a moving central station, as is being tried on one of the French lines, or those special problems like the Baltimore tunnel, in which an electric locomotive will be utilized for a short distance in place of the steam locomotive; I am considering the possibilities of what is generally considered an electric system—that is, the operation of a number of train units from a central station.

"If we were to refer a moment to any other system of transmission of power—for example, by water or air—no one for a moment would question its limitations. We all know that any amount of power can be so transmitted, but only with definite losses which depend upon the pressures used, the sizes of pipes, and the distances and amount of energy transmitted. So it is in the transmission of electricity, which is nothing more or less than an agent whose exact character we do not know, but whose obedience to certain empirical laws is absolute.

"It is unnecessary here to repeat the specific laws covering such transmission; they are perfectly well known, and there is no practical hope of their being changed, any more than the laws of gravity. Recognizing these laws, there is a distinct limitation to the distance and amount of power which can be economically and conveniently transmitted and distributed, no matter how perfect the generating or receiving machinery may be; and these two particular elements have been brought very nearly to their maximum possible efficiency.

"It may be said—which is perfectly true—that, if from a central station one can conveniently operate a number of distributed units over a 20-mile road, why cannot two or, for that matter, a dozen such systems be connected together? So they can, but this does not form a trunk-line system. Of course, if we consider the steam trunk-line from a passenger standpoint, the present system has defects, and the principal one is the inconvenience of service when considering short distances. If one is going a long distance then it matters not so much whether the trains are two or three hours apart in leaving; but long-distance travel and short-distance travel have not the same requirements so far as the passengers are concerned.

"If nothing is sacrificed, it would be preferable, of course, to have smaller units despatched at more frequent intervals, no matter what the distance of travel, but, as I say, this is less important when dealing with long distances than when dealing with short ones. When trains are operated in large units, with comparatively few units between terminal points, and these at considerable intervals, the steam locomotive will absolutely hold its own. When, however, these larger units are broken up, the intervals of train-despatching can be shortened as much as is consistent with satisfactory operation and the number of units distributed over a line made correspondingly large; then, and then only, will electricity be used on suburban lines and lines connecting important cities.

"I have again and again advanced the substance of this statement, and I must here repeat and emphasize this fact—that, so far as passenger service is concerned, considering for the moment only economy of operation, the problem narrows itself down to the number of train units operated between terminal points. Make that number sufficiently large, and the electric motor is

the best means of propulsion, whether for high or low speed. Decrease this number, and you must rely upon steam.

"Or, putting it another way, the answer to the query, will electricity take the place of steam locomotive for railway service, is: only in part, and then only when the number of units operated between terminal points is so large that the resulting economy will pay a reasonable interest on the combined cost of a central-station system of conductors and the motor equipment, and the traffic existing is commensurate with the needs of such a system.

"It is perfectly true that looking only at the time standpoint of passenger traffic it is entirely possible and feasible even, not only to operate any existing street or elevated system, and many of the suburban systems, but also the traffic between such points as New York and Philadelphia on a subdivided electric service; but this is not all that is required. The more frequent the units despatched over the track, the more exclusive must be that particular track for that particular service, and the larger must be the number of tracks to take care of all the varied service of a great system.

"Briefly, the service may be characterized as the transmission of passengers from one local point to another and the transmission at high speed between principal points—that is, way and express service—and the handling of freight in great masses with all the attendant switching and distribution at way and terminal points. Considering only the transit needs of these various services, a six-track railroad might be considered desirable, and probably would be; but there are many problems connected with such a road, to say nothing of the fact that it would often be impossible to construct such a system on existing rights-of-way. Independent of the matter of investment, rights-of-way, or construction, the problems of switching, passenger landings, and freight acceptance and delivery, on a six-track railroad would be a grave one.

"Freight cannot be handled like live loads. A succession of cars, each with twenty or thirty passengers, might well take care of all the passenger traffic on a road, but freight cannot ordinarily be handled in any such way, except by an enormous increase of expenditure. The 30-, 40-, or 50-car train, pulled by a single locomotive, with a limited train crew, presents an economical transportation of freight which no system of units on long-distance transportation can hope to equal.

"It may be contended that there is a way to create a six-track service, and that it can be operated partly electrically and partly by steam, and that the small units for way service can be run on one set of tracks, the express units on another, both subdivided, and that larger freight units at long intervals can be operated on the third, but this proposition will not appeal with any practical force to the railroad man, or to the electrical engineer as

such, because it is absolutely vital for successful electrical operation from a central station that the units shall be divided, and that there shall be a distributed service, and not a localization of large units at long intervals at any portion of the system.

"It seems hardly necessary to even refer to the question of signals, and all the difficulties which would exist if an attempt were made to operate a road simultaneously with electricity and steam. Human life and its absolute dependence on these signals, which neither natural laws, stress of accident, or conditions of weather should interfere with, make this of vital importance in considering any change.

"One of the great advantages of the electric system, as generally used, considered from a traction standpoint is the fact that the motors are carried under each individual car, or, with few exceptions, under one of two or three cars, thus giving the advantages of a higher proportion of weight for traction, with a consequent distribution instead of localization of weights. When motors reach their highest standard every car can be made an individual unit, which can be operated in any combination and from any point of a train; but this advantage instantly disappears when it is attempted to use an electric locomotive after the manner of a steam locomotive. That is, to put it ahead of a number of car units whose aggregate weight may be from five to twenty-five times its own. It must, then, in a large measure be limited by identically the same laws in the matter of weight and traction as the present steam system. Assuming units which are common on steam roads, such as 1000 or 1500 H. P., the enormous loss of energy and the variation of pressure on a line would make the cost, with any possible allowable loss, entirely impracticable.

I have seen little development in the last five years to alter those general conclusions, but I am no less a believer than ever in the gradual and certain encroachment of the electric upon steam railways. If I were asked, however, if electric traction will take place "under steam railway conditions" I would say no, except in special cases. What are steam railway conditions? A more or less perfect roadbed, which gradually becomes a more or less exclusive roadbed, and the more exclusive it becomes the better it is for electric railways; stations at predetermined positions and distances of signaling; operation on the same or on separate tracks of express and local service and freight service, which complicates the problem; operation under a fixed time-table, with varying lengths of trains, but always large units, with a tendency to larger ones. These are essentially steam railway conditions. Many of them are directly opposed to commercially successful electrical operation.

There are two things which have been brought forward and practically developed in the past three years which are not mentioned by Mr. Boynton as having a possible use in future electric

railways. The first is the storage battery. Its use on the South Side elevated in Chicago, on which I have 180 cars in operation, the experience on the Metropolitan road in this city, and the general introduction on a large number of other roads and central stations, primarily for the purpose of equalization of load and for taking a small portion of the peak load at certain hours, warrant the statement that it is certain to be a feature in railway development. There is no doubt in my own mind concerning this. Another development is the method of controlling two or more units or cars equipped with motors from a common source, which I have called and it is now known as the "multiple unit" system, subject to more or less ridicule and criticism during past years, but now being generally accepted as necessary in modern transportation. I do not mean by the term "multiple unit system" the equipment necessarily of every car in a train, but the equipment of two or more cars of a train under a simultaneous control. Neither of these developments are mentioned or considered by Mr. Boynton. If there be a question about this latter proposition, let me recite what has been proposed with eight or ten roads representing modern work. The Illinois Central Railway, with its six or possibly eight-track service, stands as an example to-day of the most perfect steam suburban service. For two years and a half at least actively, and for four or five years before that tentatively, its management has considered the application of electricity to that suburban service. Bear in mind that before we undertake the larger problems we must take that which is at hand; that is, suburban service 20 or 30 miles out of the city. So we will consider this Illinois Central road. The conclusion arrived at some two and a half years ago was that from the standpoint of steam economy nothing whatever was to be gained by the adoption of electricity under the conditions which exist in Chicago on that road at the price they paid for coal and with the duty they are getting out of the engines; that in the matter of speed, that was already very satisfactory on the express service, but for the way or suburban service electricity offered an advantage, permitting an increase from 18 to 23 miles schedule speed. But all consideration of a locomotive or a locomotive-car pulling a number of cars has been put aside for a finality. The only thought, I think I may say fairly, which they have had in mind is one expressed by the then Chief Engineer and now Assistant First Vice-President Wallace, when he said in effect to me, some two years and a half ago, that he wished to see the abolition of the time-table on suburban service, and to be able to direct at frequent and regular intervals the going out of train units of one or two or ten cars, without unnecessary switching, without a locomotive at the head to pull them, motive power and capacity always holding like proportion to each other, with orders to leave the terminus and get back there as quickly as possible, without waiting at any station for the time-table. He said: "I

hope to see cars operated by a push-button." It happened at that time that I was in Chicago, connected with the Chicago South Side elevated, and I told him that that was what I was there for. Shortly after that the equipment of the South Side road was taken up. If that road adopts electricity they will put on their cars not less than 300-horse power, and those cars will be operated in any combination from one to a dozen cars. Such radical operation requires, for the best duty, a storage battery to help equalize the load and to take perhaps a little of the peak. If alternating currents are used, with rotary transformers delivering constant potential on the line, it is out of the question to put upon the sub-stations the sharp, varying loads which would be required, without a storage battery.

The Liverpool Overhead Railway operates at present three-car trains, with motors on the front and the back car. The Waterloo and City Railway of London operates three and four-car trains, with motors on the front and back car. The Union Electric Company of Berlin has recently submitted a project to the Minister of Public Works proposing the change over from the present steam system to an electric system, working as many as 12 cars in a train, each car being equipped with two motors of 150 H. P. capacity each. The new Berlin Elevated Railway, of which Messrs. Siemens and Halske are the prime movers, are considering the operation of four and five and even up to ten-car trains, and they have had under consideration all sorts of methods—four-car trains, with three motors on the front and on the back car; four-car trains, with four motors on the front and back car; five-car trains, with two motors on the front and back car; ten-car trains, with two motors on the first and rear car and two motors on a middle car, and a full multiple unit system.

The new Boston Elevated road will have an equipment of two 150 H. P. motors per car and operate them in from two to five or six-car trains, all under a common control. The Manhattan—well, none of us can speak with any definiteness about that yet, and therefore I will not prophesy.

The Brooklyn elevated will operate from three to five-car trains, with two and three motor-cars in a train, and contemplate eventually equipping every car, all under a common control. So it would seem that in electric railways the idea of grouping together units and controlling them from a common point is the accepted engineering conclusion, no matter who does it or what the specific apparatus. If a railroad is operated either with one-car units or two-car units or six-car units all the while there would be a definite determination of the motor equipment for that unit. If instead of being constantly operated with one size train units, it is operated with trains which are made up of a varying number of units, then it seems reasonable to suppose that each of those units should be equipped with the power and only with the power that is necessary to drive them.

Some of you are suburbanites. I am not, except as to my shops. The advantages (or disadvantages) of New York are such that to get out we have either to burrow or float, go through a tunnel or go over the water, and I have often to take the Delaware, Lackawanna and Western Railway. I picked up a time-table this afternoon, and I was a little surprised at some of the conclusions which a graphic setting out of that time-table showed. You know that from Hoboken there is a two-track stem with some freight sidings that runs to Newark and up to the Roseville Avenue Junction. Thence a branch goes to Montclair. From Roseville avenue the main stem of the road runs out to Summit, Morristown, Dover and on. Taking the latest time-table, I have laid out the trains on a graphic method, based on number of trains and times of transit. The distance from Hoboken to Roseville Avenue is about nine miles, thence to Montclair four miles, and from Roseville avenue to Morristown 21 miles. This road may be taken as typically representative of a suburban service, and is right at hand. At present one crosses the ferry every 10 or 15 minutes and finds a train every 40 minutes or every hour and 10 minutes, just as one goes on the Manhattan elevated to 155th street and then finds trains to Yonkers anywhere from 10 minutes, to an hour and 10 minutes apart. The aggregate roadway here considered, is roughly 34 miles, and the actual single trackage about 66 miles. Between about five o'clock in the morning and one o'clock at night there are 144 trains in operation on either a part or the whole of the distance over those lines from Hoboken to Montclair, or to Morristown, 31 miles away, leaving out those trains which go beyond Morristown. I have considered their limit of service because it is within the reasonable limits of transmission of an alternating current from a reasonable center. Perhaps it would surprise you to know that despite that number of trains there are times—considering no stoppages whatever at a station, but only the time from departure to arriving—between five o'clock in the morning and one o'clock at night when there is only one train on this 66 miles of track. That is a steam railway condition, but not one which will ever be adhered to if the road adopts electricity. Considering the stoppages of trains at the different stations, there are probably not less than 20 times during these hours in which there is not a car moving in all those 144 trains that operate within the 30-mile radius of Hoboken—not less than 20 times within the day when there is not a wheel turning on 66 miles of track, despite the fact that this road is supplying 20 or 25 populous suburban towns. It has been said that that road is considering the adoption of electricity. It is a perfectly practicable engineering problem and entirely feasible commercially. As at present run there are but from 1 to 13 trains in service, and from about 3 to 65 cars maximum. The equipment to get the best service should be with not less than one-half of its cars equipped with motors, and I question

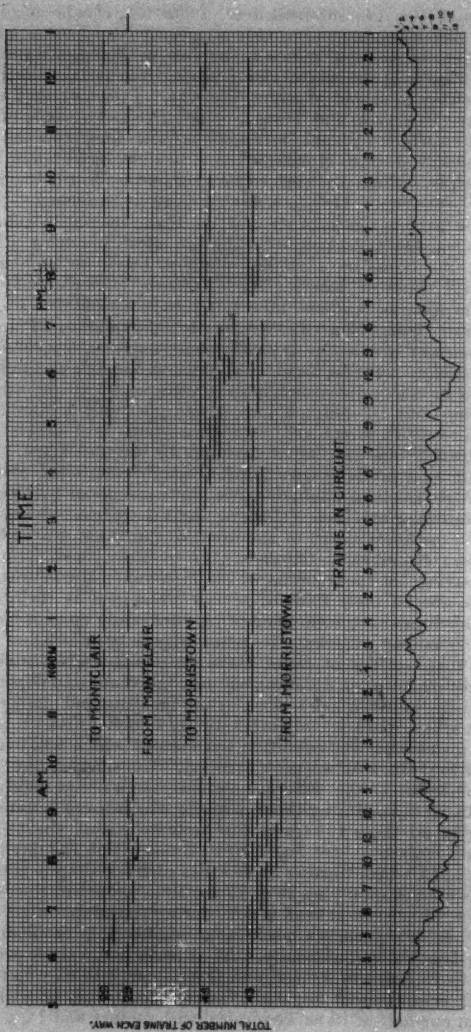


FIG. 1.—Train Time Diagram, D. L. & W. R. R. Suburban Trains to Montclair and Morristown, and Between.

if it would not be better if every one of its passenger cars were, but certainly not less than one-half.

There are two things you have got to consider in traffic. One is to meet the wants of the individual man. He cares little what anybody else wants He goes to a station and wants to go home or to business. The other is to meet the collective wants of these several men. Scattered throughout the day there is a fair average of people who wish to travel, and at certain hours of the day there are large numbers of people who have a similar desire. So we have to consider not only the frequent dispatching of trains, but the variation in size of those trains. If one-half of the standard coaches on a road were equipped with motors under conditions that would make it possible to operate two or a dozen cars under simultaneous control, the cost of the car equipments would probably not exceed one-quarter the cost of a single one of the generating units required for the Manhattan Railway, including its engine, steam piping, and proportion of building. The power required to operate this 34 miles of suburban road would be equal to about two of the Manhattan units, and but very little more than is being used on the South Side elevated in Chicago.

It seems to me that the broad question of using electricity on a road is one which is to be determined absolutely by the frequency of service which that road will stand, and the more the short-distance trains are operated electrically the fewer the steam trains going to long-distance points, which must operate over that road. I will content myself by simply prophesying two facts: one is that the storage battery is a necessity in any large development of the application of electricity to railroads, and the other, that the aggregation and control of two or more units in a train—that is, the multiple unit system will be the future method of operation. [Applause.]

DR. CARY T. HUTCHINSON:—I think Mr. Sprague has entirely misunderstood the intent of this paper. I do not think it is intended to discuss broadly the most economical method of operating trains by electricity, but was intended as a resumé of the author's experience in handling suburban trains; and it tells what the author has learned. There is no intimation whatever in the paper that any consideration of the economics underlying electric railway service was intended; but there are many interesting results of his experience; among others, the very low cost of repair of electric locomotives, only ten per cent. of that for steam locomotives. I do not think this would hold as an average result or even an approximation. The figure of four to six kilowatt hours per train mile for train service without mentioning at all the weight of the train or the schedule is indefinite. It is generally understood that the energy consumption per ton-mile may vary in the ratio of 1 to 10 for different schedules.

There are a number of other facts of that kind that might be discussed, in particular, the performance of motors, etc., for above ratio. What is the ratio?

Mr. George T. Hanchett:—I note in the paper that Mr. Boynton mentions an 800-h. p. equipment of four motors. That means a 200-h. p. motor. I had the good fortune to observe the experience of a prominent company manufacturing railway motors of that capacity. They were used in elevated work. They were installed within a 6-foot wheel base with a 33-inch wheel. They filled the space. There was hardly room enough for the brake rods. The motors had to be mounted on an odd angle in order to allow the car axle to thread through the casing between the pole-pieces. It was found necessary to keep these motors open both above and below the bearing on both sides in order to safely rate them at 200 h. p. If I remember correctly, the temperature rise was something like 75 degrees centigrade above the atmosphere. If those are the facts it is necessary to keep the casings open if we are to use 200-h. p. motors in such work. Such ventilation was mentioned by Mr. Boynton as a luxury which might be enjoyed under certain circumstances, but I think it is a necessity if the experience of this company is to be believed.

Mr. Richard Lamb:—Speaking of open motors in suburban service, I have recently been called upon to build a trolley line at Brigantine Beach, N. J. The ocean had cut away the beach, leaving the trestle out from the shore a distance of about 200 feet. One of their experiences was that when the tide was in and the waves were high they would have an armature short-circuited and burned by the salt spray entering the open motor. On one occasion they had one of their large generators in the power-house thrown off of its foundation, from the ocean spray short-circuiting an open motor on a car two miles from the station, the circuit-breaker having failed to work. They also had the experience of the sand blown into the open motor by the winds, cutting away their commutators and journals. They tried putting what they called a canvas petticoat around the opening of the motor. This raised the temperature excessively. These experiences prove the absolute necessity of using completely encased motors in any suburban service having seashore road-beds.

Mr. Elias E. Ries:—Mr. Boynton, in his paper, although he mentions and describes the various methods he speaks of as relating to the operation of electric railways "under steam railway conditions," it seems has confined himself more or less to short lengths of lines of about 10 or 12 miles, such as are and have for some years been successfully operated by direct or continuous currents. The application of electricity to such short lines of steam railroads I should regard as operating steam roads "under electric railway conditions," rather than under steam railway conditions. I believe that the thing which electricians

and engineers in general have chiefly in mind when it comes to the question of substituting electricity for steam on railroads is the electrical operation of long lines, or trunk lines. That, it seems to me, can only be successfully accomplished when we have arrived at the point when we can supply alternating currents of high tension for transmission purposes and convert these into currents of lower tension for the operation of the motors. This matter is incidentally touched upon in Mr. Boynton's paper, but very little has been said here to-night in regard to it. It is a subject, however, too lengthy to be discussed at this late hour and I will therefore pass it by, notwithstanding that I believe the solution of this problem necessarily rests upon the adoption of such a system.

There was one interesting point mentioned by Mr. Sprague in his discussion, stating his belief that in any rotary converter system operated by high potential currents for long distances, it would be necessary to combine with it a storage battery. It struck me that there was an interesting possibility in that application when you come to the question of the general problem of operating trunk lines or long-distance railway lines with infrequent long-train service by electricity, and that is this: The great difficulty in adapting electricity to steam railway operations is that the present steam locomotives are fairly economical because they carry along their own generating capacity, which is not only sufficient for, but is applied locally to, the work of hauling the train; they require a certain crew, limited in number, and their most economical condition of operation is to haul as heavy a load as the traction ability of the locomotive can sustain. The electric system, on the other hand, which requires fixed stations for generating current that must be transmitted over the line whether there be only one or a dozen trains on a section, demands that its generators be operated at the highest efficiency—that is to say, at practically full load at all times, preferably 24 hours out of the 24, and it would be a great waste if those generators, which must necessarily be given a power capacity greater than that required to move the heaviest single train at the required speed, had to remain idle for a period of anywhere from one to four or five hours at a time between trains.

Now, it strikes me that it is just possible that a system of generating stations could be combined with a storage-battery plant in which the battery would be used, not merely for compensating for the difference between the peak of the load and the level load; but it could be charged by generators of rather moderate power running all the time, the battery groups being so connected as to give forth their energy for comparatively brief periods in large amounts (to feed long, heavy traffic trains running approximately under steam-railway schedule conditions at more or less infrequent intervals), on the principle of the accumulator in a hydraulic system, or the flywheel in a

punching press, etc. In that case the current might be generated and transmitted as a continuous current, feeding, at intervals along the line, storage batteries connected in series, and the latter might be arranged to automatically discharge into the service or working circuits in multiple, at ordinary working pressures, whenever a section is entered upon by a train, and so on. I merely mention this as a passing thought—that that seems to be one way in which the existing steam-railway conditions could be maintained under electrical operation *if* it were desirable to do so. I do not advance this, however, as a desirable solution by any means, as I believe it will be found better to modify steam-railway conditions so as to conform to what has been found best in electric practice. It simply occurred to me and I thought I might mention that as an interesting possibility. The general subject is one of considerable importance, and I am very glad, indeed, to have heard the INSTITUTE discuss the matter so fully this evening.

THE SECRETARY:—There have been some criticisms on the title of this paper, and whether they are just or not, I am not certain that it should be left for the author to defend, because whatever the title is, it was originally suggested to him, and then after he adopted it, it was changed; and, as a matter of fact, I do not think he is responsible for the title at all. What this is, and what it was attempted to get, is some notes or some information in regard to the operation of trains by electricity, over the same road and under the same conditions where they had previously been run by steam. Perhaps some of you may be able to fit a title to those conditions, for that was what the Committee on Papers was trying to get at, and it went to the only known place in this vicinity where electric trains were operating under those circumstances.

There are certain interesting questions involved in such a radical change of operating conditions as noted in this paper. I served on a railroad for two years before I went into telegraph work, and I have ridden on a steam railroad as a suburbanite for 33 years, and I can speak as a practitioner in early days, and an interested observer of modern methods. I have recently had an opportunity of comparing a steam express service with a fifteen minute interval and a trolley occasionally connecting with it on a twenty minutes headway. But the superintendent found that they could not quite make the schedule under all conditions. He said that if things were all right, that they could make the time under twenty minutes headway. But sometimes things happened—cattle or old women or wagons got on the track and delayed the cars, so they changed the schedule to 22 minutes, making it 66 minutes in the hour, as you might say. It has been a problem ever since that road changed its schedule about six weeks ago for the people on the side streets to find out when a car would be along.

It appears to me that people who undertake to manage a service of that kind should study the conditions of life and the conditions under which people travel on the cars, as well as taking up the technical questions, because in this particular case there is a great deal of traffic comes on the connecting steam railroad.

It is not so much the question of the time-table as it is having the cars run at regular intervals in each hour. If they run every 30 minutes and start on the even hour, you know there is one every half hour; that is all right; all that is perfectly clear and easy, and so it is when they run every 20 minutes or every 15 minutes; but when they run every 22 minutes, making a variation of six minutes in every hour, it begins to be a brain-racking performance to keep track of it.

Getting down to some of the technical points that are brought up by Mr. Boynton, he mentioned this third rail, and the difficulties of bonding with that particular form of rail, and it occurred to me that it would be a very simple matter, if there was any amount of business in this, to make a form of rail for a conductor that would be satisfactory. Then there is a question as to the position of this third rail, whether it is to be outside of the two rails or between them, or near to one, or in the center. I do not see any information in the paper as to the best position.

In regard to ice on the track, while we have comparatively little of it, it does not appear to me that this is an argument against the use of electricity. Where it is an annoyance, and in certain climates it would probably be worse than it is around here, it appears to me that it could be gotten over very readily by an economical device. Even if this could not be done, we might as well say that the locomotive is a failure, because sometimes it gets snowed in, as it does, and becomes one of the most helpless pieces of machinery that you can imagine, when it is packed in the snow. Regarding speed possibilities, I would like to inquire as to the distance required for getting up the speed of these short trains, for this reason, that a few years ago, when what was then a record run of 72 miles an hour, was made on the Bound Brook route, that train ran 12 miles before attaining that speed. I believe there is only one place on that line where the track is in such condition that they can make such time, and of course when you consider that it takes 12 miles, as it did at that time, why of course frequent stops make it practically impossible, and it appears to me that before dismissing the subject, we ought to consider this question of speed a little more, because it is very important, as some of the predictions in regard to the speed of electric locomotives have not been verified in practice. The probabilities are that one of the reasons is that there are very few lines in the country that are well enough built and have a sufficiently long stretch of reasonably straight and level track so that they can attain the speed that we have had in contemplation.

MR. HARRISON ANDERSON:—I came here this evening as a stranger and guest, and one of my reasons for coming was that I am browsing around everywhere. I came in search of information and instruction, and I like my instruction very much as I like my whiskey—I like it straight; and I can illustrate what I mean by an experience that I had a couple of years ago in the west, when I was trying to sell a very fast steamboat to Mr. J. J. Hill, of the Great Northern. While we were out on this steamboat together, naturally, Mr. Hill instead of talking about my steamboat was talking about his own railroad. I was very willing to listen. He said: "You can write the whole secret of successful railroad operation on your thumb nail. I have men who have been in my service for twenty years and have not got down to the fundamental facts of successful steam-railroad operation. It is that expenses are by the train mile and receipts are by the ton mile. That is all there is to successful railroad operation." I came here this evening hoping that I would hear some formula of that kind that would give me an absolute grasp of the successful operation of electricity as replacing steam on the railroads.

MR. SPRAGUE:—Possibly I can give the gentleman some information on that point. The South Side road in Chicago, of which I have spoken, was a steam road operated by Baldwin 28-ton compound locomotives, hauling from two to five cars. The saving at the present time is about $500 a day for coal alone. They are also saving in transportation expenses. The actual cost of the operation of the road, exclusive of taxes and licenses, is seven and a half cents per car mile of 22 tons average weight, including passengers, and stopping at intervals of about 2,000 feet, on a schedule of 15 miles an hour.

No one here has spoken of the somewhat interesting experiment made in Germany on long-distance transmission. Mr. Reichel, the chief engineer of the Siemens and Halske Company, was here a short time ago and he told me of some experiments he had carried on in the transmission of an alternating current at 10,000 volts over a small line, from which the current was taken directly to the locomotive, on which was a transformer, connected with which was an alternating current motor. His object, of course, was the reduction of the cost of transmission for spasmodic service over long distances, and with a small arc of contact to get a large amount of energy from a small overhead wire. I do not know how successful the experiment was, but it at least was tried. But on the new Berlin elevated railroad they are going to use the continuous current at 700 volts.

I notice, speaking about the cost of some things, that $80 to $90 was given as the cost of the central station per kilowatt output. The cost in the stations laid out in this city at present is over $200 per kilowatt, including engines, dynamos, switchboards and such proportion of the building as is required to

cover that particular unit. There has been some rise in prices in the matter of machinery recently.

On some elevated roads ice is kept from the third rail by running a fast car or train over the lines on seeing the approach of sleet. With the more or less reliable weather prognostications, it becomes possible generally for a good weather man to state whether he is going to have sleet on the track or not, and sometimes they run over the line and grease the third rail. That is done on the Brooklyn Bridge. It is sometimes done on the main section of the Fifth Avenue road. Where there are a number of cars in operation, and the main current is carried from car to car, then the shoes on the forward car are apt to break the sleet, and those on rear cars do their duty of supplying the main current. I have seen five cars coupled together in a train on a track very heavily coated with sleet, in which the forward cars broke the sleet coat completely, and there was scarcely an arc of any kind on the brushes which made the actual connection, because there were so many connected together.

Mr. George F. Atwood:—I would like to ask Mr. Sprague or Mr. Boynton if there has ever been any other form of collecting shoe tried than the ordinary type of shoe?

Mr. Sprague:—I do not know of any that has been tried in every day use. The Union Electric company of Berlin proposed the use of a side shoe. Sleet is not always formed on the top of the conductor alone. It is oftentimes formed on the side by the wind drift. In Boston proposals were originally made for covering the tracks with a sort of shed. I don't think that will be carried out. The project in Berlin calls for a covered track, but I doubt if that will be finally adopted. Where you have a number of trains in operation and can connect cars, you can almost always overcome any sleet storm which may occur.

Mr. Atwood:—You never use a rotary shoe, a side pressing shoe?

Mr. Sprague:—Not that I am aware of. I used wheels myself as long ago as eight years, on some experiments on the Third Avenue elevated, 34th street; but the ordinary sliding shoe is more satisfactory.

Mr. C. O. Mailloux:—I would like to have Mr. Sprague explain the difference, if any, in acceleration obtained with his system of multiple control, as compared with the ordinary control system. I have understood that there were advantages claimed for it, in so much that it enables the car to accelerate faster, or to reach its full speed sooner. This is a matter of extreme importance in rapid transit, such as would be suitable for an elevated road. I had occasion to study the matter two or three years ago when they first discussed the matter of equipping the road, and discovered, much to my surprise, though it might have been easily anticipated from theory that there are limitations to the average or schedule speed (in miles per hour)

which it is possible to obtain on the elevated road, owing to the limitations of the velocity of acceleration. I was told at the time that Mr. Sprague was enabled to accelerate his cars faster, and that by being able to do so he was able to shorten slightly the schedule time between two stations.

MR. SPRAGUE:—I will give you an exact comparison. As to curves and grades the Manhattan elevated and the Brooklyn elevated are almost identical in their conditions, and require about the same energy per ton-mile for any given schedule. On a six-car train, a schedule of about 13½ miles an hour, when the train is loaded, is barely possible with a locomotive car weighing about 40 tons equipped with four motors of the largest size which are practical to put under a car. They would be rated at 600-horse power, but that is excessive rating, considering the thermal characteristics, and they could not stand the service. If instead of the proportion of weights on the drivers that that locomotive would give, these six cars are equipped, each car with two 80-horse power motors, it would be perfectly possible to go to a 16½ mile schedule, or if equipped with two 50-horse power motors, making the same aggregate motor capacity on a six-car train which it is possible to get with a locomotive car, a 15 mile schedule can be made with the distributed motor equipment, with identically the same power at the central station as would be required to make a schedule of 13½ miles with the 600-horse power localized on one car.

If the schedule of 13½ miles were only required with the distributed motors, there would be a reduction of about a million and a half dollars in the cost of delivering current to the car-shoe.

These are briefly the results of a good many calculations which have been made with reference to roads with these particular conditions. The reason is that there are three kinds of work; lifting of a car on an up-grade, which is independent of the schedule; simple traction, which is so much per ton, and is also perfectly independent of the schedule, except as the air pressure affects it; and inertia, which is put into a car and thrown away in braking. If you can get a car up to a certain speed, cut off the current, and then coast to a stop, it would be just as well to run the car that way as to go to some less speed, then run along at a constant speed, and coast without any braking to a stop. The energy put into a car for the purpose of getting up speed varies as the square of the speed, so that the difference in inertia energy between 20 and 25 miles is as 400 to 625. Under the conditions existing on the elevated railroads here and in Brooklyn, and for quite a range of schedules, the energy per ton-mile varies nearly as the cube of the schedule speed. It runs up rather rapidly. About the most economical speed with the existing station distances stops and grades is about 16 miles.

MR. BOYNTON:—There have been so many criticisms on this paper that it is impossible to reply to them all in the short time that is left. I would say that I was much interested in Mr. Sprague's address on the subject, and have gained considerable information. I am not quite able to associate the multiple unit system of control with every condition of steam railroading. But there is no doubt that for most of the suburban conditions of traffic in cities it is applicable.

The traffic with which perhaps I have had more to do than any other is not exactly similar to suburban traffic. It is a traffic that does not consist of a great many trains running on frequent schedule. If one goes to a steam railway manager and proposes to equip a certain section of his line with electricity, one can tell him all the different methods of employing electrical apparatus, but he will inquire about dollars and cents. He will place that at the bottom of every proposition you bring up. If he has a million passengers to transport from one place to another in a year and you tell him that you can do it for considerably less than it is costing, then he will listen to what you have to say with interest. Nearly every one with whom I have come in contact in railroad business emphasizes that point. Of course it is the practical place to look. That is the principal reason why a sentence in the paper reads as follows: "It is considered probable that a given number of passengers can be transported cheaper with an electric locomotive hauling a train of idle cars, than if all the cars or two or three of them were motor cars." The probability is that the total weight of the train would be less. The above statement is merely an opinion, for no tests have ever been made of the two systems, where the trains are composed of standard steam railroad coaches. It would seem as if the locomotive train would be considerably lighter as it is relieved of the weight of many motors and equipments.

I differ slightly from Mr. Sprague in one other particular. Mr. Sprague remarked that he did not think that electric traction would take place under what are now known as steam railway conditions; that is, it will not take place in the future under existing steam railway methods. I think it will have to begin in that way and perhaps gradually develop into a multiple unit system afterwards if traffic warrants it. There are a number of roads that are running under steam railway conditions; electric trains and steam trains running on the same track; with sometimes only two minutes leeway between the electric and the steam trains. A practical point brought out by one or two speakers, that the service should require no time table, is a very important point. If the trains run at regular intervals, like 5, 10, or 15 minutes headway, no time table is necessary then, and the public appreciates it.

The use of storage batteries is undoubtedly going to increase. It is going to increase in more than one way. I have spoken of

a road that is run without feeders. We are at present installing a storage battery on the end of the road, connecting it right across the end of the line. The train service is such that that battery can be kept fully charged by utilizing the current when no trains are on that end of the line. Its tendency is of course to even up the potential along the line. Such a method of feeding a railroad, if you choose, is much cheaper as regards first cost than putting in a feeder of metal.

In regard to some of the other criticisms, I am obliged to Mr. Pope for clearing up the title of the paper. The object in writing it was simply to bring out a discussion of various points. As to some of the figures in the paper, I did not think it was necessary to add a foot note to the effect that an employee of a corporation, such as I am, is not always allowed to give out exact figures. Therefore, if I said from four to six kilowatt hours per train mile, and the actual figures obtained from tests with a wattmeter, voltmeter and ammeter on an a train was 5 1; I prefer to say four to six instead of 5.1, and by carefully reading certain parts of the paper, it will be seen that the length and weight of the trains, under consideration are stated with sufficient clearness. When it is said that power stations are built for $80 or $90 a kilowatt, perhaps I might say that I have seen one built for $88—a large one at that, within three years.

MR. SPRAGUE:—I did not mean to say that the multiple unit system was the one system applicable to *all* conditions of railway work. A great many conditions must necessarily be met in specific cases. What I had more particularly in mind was the handling of suburban passenger service, which is the first elemental step from trolleys into steam railroad fields, and also I would not have it understood that I do not believe in the thorough practicability of operating steam cars over the same tracks as electrics. I have had 50 of each on the same tracks.

MR. RIES:—I should like to have Mr. Boynton inform us if he will, as to the frequency of the train service on the particular line which he refers to, and of which he has charge. That is to say, how many trains are actually driven from the generating station at the same time, whether there is any lull worth speaking of between them, or whether the schedule is so arranged that the generating station has a practically constant load upon it at all times. That would throw some considerable light on the subject of the advantage on the line in question, of the train unit operations, that is, as to the relative merits of individual small units or long train units.

MR. BOYNTON:—I would state that I have a general supervision of several lines, and they are all different. The heaviest one, and the one that carries the most passengers, is perhaps more referred to than others. The train service on that line is half hourly, and to reduce it to the basis of the paper it means a half-hour train from each end of a 10-mile run passing in the middle. But there are other portions of the road dependent

upon the same power station, so that in the summer, with the electric heaters off, the load will vary perhaps from 200 amperes, which practically means one train, to 800, which practically means four trains, and of course the starting of that number of trains will run this up considerably higher for a few moments. Mr. Pope and others have mentioned the subject of ice on the rail, and it is with us a most important subject, and I think to almost all railroads using this kind of a rail. Ordinary sleet, the shoes and stiff wire brushes will scrape off; there is no doubt about that. But there is a kind of sleet which I tried to describe in the paper (perhaps I did not succeed), which we will call a coat of varnish, and you cannot get it off with an ax. You can chop it, and do anything you please to it, and it sticks like a brother. Nothing will move it, apparently, until the temperature changes and it loosens up, and if I am not mistaken, some of our elevated roads this winter have been tied up more than once from that very cause. Take that kind of ice and strike it with a knife or an ax, and you make a slot across it, which shows just where the edge struck it. Strike it in half a dozen other places, and you make half a dozen marks, and the sleet between the marks is stuck just as tight as it was before, and that is the kind of sleet which is hard to remove. Sleet that you can strike a blow, and it will fly off, gives no trouble. Upon such questions as this depends the successful operation of the road, and when the weather or some other unforseen circumstance ties up the road for a few hours, it is rather humiliating, to say the least.

I have recently been experimenting on methods of removing sleet from the track, using various substances upon the contact surface of the rail to prevent the ice from sticking to it, no matter what the temperature is. I have seen the railroad freeze up in five minutes when it was raining. I have seen a car go through and the next car behind it was stopped. I have recently tried a piece of tool steel consisting of a plate three-quarters of an inch thick and perhaps ten inches square, sliding in grooves, controlled by a lever, by which you can push the plate down on the top of the rail in a vertical position. As far as we have tested such a thing it takes everything off the rail, almost including a chip off the steel rail, and it keeps itself sharp, so that it looks as if the problem was pretty nearly solved; but there are certain matters that have to be perfected, for instance, it is almost absolutely necessary to slide the plate vertically, just as near the vertical as you dare, and then it will cut and will keep itself sharp, but if it is back of the vertical it loses a good deal of its cutting power, and it must also be so arranged that when it strikes a joint or a break in the rail, it can back off and jump over and come forward again, which can be done by means of powerful springs. Those little points seem unimportant, but they are vital in running a road, and I am not aware that they have been solved yet.

[Adjourned.]

DISCUSSION AT CHICAGO, FEBRUARY 28, 1900.

MR. BION J. ARNOLD:—We recognize in Mr. Boynton's paper a careful analysis of the relative advantages of steam and electric traction, and a concise digest of the present practice in constant potential direct current railway work. Inasmuch as the paper gives the results of Mr. Boynton's experience on a heavy direct current line, it is of special interest and benefit to electrical engineers, and should be to railway officials contemplating the equipment of their lines electrically.

However, owing to the present state of transition, being as we are, between the direct current road and the alternating current road, it is hardly safe for any one to take a positive stand and assume that we are going to confine ourselves in the future to a direct current road. Mr. Boynton's paper seems to point out many difficulties for which he is seeking solutions, that would not be present in case the alternating system were adopted. I refer especially to rail bonding; to the question of working conductors, and the feeder system. It is possible that in the near future we shall see the direct current largely abandoned for new construction, and our long distance roads operating with alternating motors, probably at much higher voltages than at present seem practicable. In fact, it seems essential to increase the trolley voltage, if we are going to handle the heavy trains mentioned by Mr. Boynton, at high average speeds. When we consider that in order to make an average speed of 45 miles an hour with a train weighing 100 tons, stopping an average of once every three miles, it requires a maximum capacity of 1600-horse power on each train, it will readily be seen that the amount of current at 700 volts becomes greater than can be carried by any reasonable amount of copper, and by any known means of contact shoes or trolley wheels. This also applies to the bonding of the rails. For this reason the only practicable way is to increase the voltage of the working conductors, thus cutting down the current, and the cost of transmission lines.

Regarding the cars, it occurs to me that the most probable solution will be the adoption of heavy cars for through traffic, equipped with motors designed especially for long runs and few stops, and lighter cars for the local or feeder service; this being practically the style of equipment that is adopted by steam railroads for similar work. Each car would be a motor car in itself. If the heavy train should ever be used for high average speed, and numerous stops, it seems necessary to equip each axle of each car with motors, for the reason that it is impossible to get sufficient adhesion to accelerate the train rapidly from but two pairs of traction wheels on each car.

MR. R. H. PIERCE:—I agree with Mr. Arnold that this paper is most interesting as showing the present state of the art; but it seems extremely doubtful if it will enable us to draw any general conclusions as to what will be done in the near future in electrical railroading.

In figuring over a number of propositions where it has been proposed to use electricity for heavy trains at a high rate of speed, I have always been forced to the conclusion that it was economical to resort to polyphase transmission for distances considerably less than 10 or 12 miles. I believe in most cases we will reach the limit at about one-half that distance. The distance at which you can transmit with direct current in many cases is shortened up by grades which call for heavy current, in cases like those mentioned by Mr. Boynton, or even those mentioned by Mr. Arnold. Of course in each special case the distance at which it is economical to transmit with a direct current depends upon the grades, and also upon the cost of producing power in that locality.

Although it is true as Mr. Boynton says that up to the present time it has been impossible to operate trains with alternating current motors, it seems as if the possibility of a solution of this problem in the near future ought to be considered in designing an electric road of this kind; and I am inclined to believe that the equipment of a road to-day with polyphase generators of low frequency may be considered a conservative step in view of the possible, and not improbable, developments of the alternating current motor in the near future. Of course such a system at present would mean the use of sub-stations with rotary transformers, as referred to by Mr. Boynton.

Inasmuch as I stand in Mr. Boynton's place here this evening it is hardly becoming in me to criticise any of his statements, but it would seem as if there might be a difference of opinion on some of his conclusions as to the best methods of obtaining certain results. In speaking of the matter of feeders, he comes to the conclusion that steel is cheaper and more satisfactory. I doubt if experience has shown this to be so. Where steel has been used for feeders in the past, second-hand rails have frequently been used, and when you consider the difficulty of bonding these, as fully explained by Mr. Boynton, it is evident that these rail circuits have been very poor conductors. There seems to be a great scarcity of data on this subject. I note that one of the leading authorities assumes that a steel rail will have a conductivity of one-sixth that of copper, of equal weight; and this figure has often been taken for granted by railroad men. I note, however, that in a paper which was read not long ago before the Institution of Electrical Engineers of Great Britain the figures showed that the conductivity of steel was in many cases, only one-tenth or one-twelfth that of copper. When the resistance of the bond is taken into consideration and the cost of bonding, which Mr. Boynton says is $2 a joint for heavy bonding, I think it probable that many of the steel circuits which have been put up, have proven more expensive than copper would have been. At the present market price it seems that aluminium is cheaper than copper, and probably cheaper than steel.

In regard to the electric lighting of stations, it seems to me that an enterprising electric light company could furnish a satisfactory light cheaper than the railroad company could do it by the method shown here. This method contemplates the use of 120 volts for lighting, and the throwing away of the difference between that and about 700 volts in resistance, which would make an efficiency of only about 20 per cent:, discarding the loss in the battery, and at the same time calling for an investment of $900 on a 60-light plant which would be an investment of about $300 per kilowatt. There are other successful ways of producing cheap lights at present.

This reminds me of one case where a station agent very carefully figured out how much he could save over the use of gas by purchasing electric light from a local company. He sent his report in to headquarters, and was informed that after figuring it over they had come to the conclusion that he could save still more by burning kerosene, and therefore he should discontinue the use of gas.

Mr. Geo. M. Myers:—I move a vote of thanks to Mr. Boynton for his very able, instructive and interesting paper.

Motion carried unanimously, and the meeting adjourned.

[Communicated after Adjournment by M. H. Gerry, Jr.]

The paper of Mr. E. C. Boynton contains much interesting information, and is a valuable addition to the literature of this subject. Its title, however, suggests to the writer the pertinent question, which has often occurred to him in considering electric traction problems, whether it is well to follow too closely the precedents established by practice in railroading under the present steam *locomotive* conditions. Certainly, practice long established and demonstrated as correct, should not be lightly cast aside without good reason, but in this case it is well also to consider the changed conditions which electric power introduces.

Modern railroading is the result of a vast amount of practical experience in adapting *direct steam power* to the economical transportation of freight and passengers. It is both interesting and instructive, however, to remember that the early attempts at steam locomotion were in the line of traction engines, and were directed to adapting the new motive power to common roads and wagon conditions. Even after steam was applied to the early tramways, we can trace from the old prints the natural attempt to adapt the stage coach to the new order of things.

Everyone is familiar with the later metamorphose of the street railway. We have seen the small horse car, without trucks, and running on light flat rails, pass away, and its place taken by the modern electric car on the heavy track construction of to-day. The new motive power made possible a desirable change in op-

erating conditions in the direction of better and more efficient service, and this in turn, has had its effect, and has extended the business to its present vast proportions. This development has been due, not to a saving of so much per car mile, but to the greatly increased traffic resulting from the better and faster service.

All this applies to steam railways in a certain degree. The traffic on many lines is becoming congested at times, and there is an ever-increasing demand for faster service both for freight and passengers. The speed of all freight trains and the number of *fast freight* trains in service has increased enormously in late years, and there is an ever growing demand for such service, as railway traffic-men know. To meet these conditions the railroads are adopting very heavy locomotives in order to obtain sufficient power and traction, and have been further forced to reduce the weight of their fast passenger and freight trains. Now, this sacrifices economy, because in operating under *locomotive* conditions the heaviest train is always the cheapest train. Speed, however, is demanded, and it is impossible to obtain locomotives of sufficient power and traction to haul the heavy trains at high speeds. Even if locomotives of vastly greater weight and power could be obtained, and the track and bridges made sufficiently strong to support them, still a point in speed is soon reached when the weight hauled behind the locomotive becomes too small to be profitably handled; that is, the weight of the locomotive and tender becomes abnormally great, compared with the train. It is possible to obtain from steam locomotives, about any practicable speed (seventy or eighty miles are common enough), but the difficulty is to accelerate and haul a train of sufficient weight to make it pay. Here we reach the limit of profitable speed with locomotive power.

The entire weight of engine and tender is of course dead load, and in fast service becomes of great importance. The writer averaged the train weights, the engine and tender weights, and the speeds from the fastest passenger train in service on each of ten representative American roads, and found the average speed at about forty miles per hour, and the locomotive and tender weights about forty per cent. of the weight of the train behind the tender. In special fast mail service, and sometimes in suburban passenger service, the percentage is even greater. The writer called especial attention to this matter of locomotive traction and dead weight in a paper before this INSTITUTE in 1897.*

Another consideration of importance is the accepted fact among railroad men that to successfully handle a large number of trains, it is essential to keep the average speed nearly the same; the greater the number of trains, the more important this

*TRANSACTIONS, 1897, vol. xiv., p. 353.

becomes Hence, of late years there has been a general speeding up of all trains, and this speed problem is one of the most serious which railroad men have to face.

Now, what relation has the above to the question of electric motive power? Just this, that there is a call at the present time for an improved service, and that it is becoming more and more difficult with steam locomotives to keep pace with the ever-increasing demands of railway transportation. Hence, there is a field for electrical motive power, in a direction where it is known to have great advantages.

Electrical traction means centralization of the power generating machinery. The more this centralization takes place, the greater the advantage. Electrical transmission has developed until fifty or sixty miles is an entirely practicable distance for transmitting power. Thus the generating stations may be from one hundred to one hundred and twenty miles apart, and this distance is sufficient for all practical purposes. The chief difficulty is not now in generating or transmitting the power as alternating current, but in its utilization in railway motors. To make use of direct current motors, involves the establishment of rotary-converter sub-stations, and this not only introduces serious complications, but it counteracts to a material extent, the advantages gained by long distance transmission. The first great need at this time, in connection with the introduction of electric power on long railway lines, is the adaptation of the alternating motor to this service. That this can be done the writer has no doubt whatever. The subject has not had the wide consideration which it merits, in view of the possibilities it would open up for the introduction of electric motive power. There seems to be quite a general impression among engineers who have not especially considered the matter, that there is some inherent reason why an alternating current motor cannot be used. Such impressions are erroneous. The induction motor has simply not been especially developed in this line. It is certainly about the best all-around motor for power purposes, and by virtue of its remarkable simplicity and other desirable qualities, it is especially fitted for the heavier and faster railway service. The double conductor required is not a serious objection, except, perhaps, on overhead trolley lines. An induction motor is, in many respects, a much more flexible machine than the ordinary series railway motor, and it can be so designed as to give a better form of speed and torque curve for most kinds of railway service. There are difficulties in the matter of control, but they are relatively less than those which have been more or less successfully met in the case of the series direct current motor. It should be borne in mind that the induction motor has been developed thus far as a stationary motor with special view to obtaining constant speed, high efficiency and high power factor. To adapt the inductive motor to railway purposes, will of course require a considerable amount

of development work, but in view of the great benefits to be derived, it would seem to be justified. Whenever the alternating current motor is perfected for railway work, all the other problems in connection with the transmission and distribution of power through the transformers can be quite readily solved.

In regard to the methods of applying the motors to the train, the writer holds to the opinion that for general purposes the *locomotive* construction should be abandoned, and the motors placed on the cars (preferably on every car, but not necessarily so), and controlled from the head of the train. This is both theoretically and practically the best method, and will especially apply to the railway conditions mentioned in the first part of this discussion. Railway motors may yet be as simple as air-brake apparatus, and when this comes there will be a great development in applying electric power to standard railways. It is the alternating current motor that we need now.

If electric power is ever applied largely to standard railways the writer fully believes it will work a revolution in railway methods, and that there will be a decided change in the design of rolling stock. Such great and important changes must come slowly, still the general adoption of electric motors may not be as far off as we suppose at this time.

Helena, Mont., March, 1900.

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 17th, 1900. President Herring in the Chair.

CONDITIONS OF ELECTROLYTIC CORROSION IN BROOKLYN.

BY SAMUEL SHELDON.

The borough of Brooklyn spreads over 60 square miles, and is covered with a network of surface trolley tracks. During the rush hours about 1,100 cars run upon these tracks and are supplied with current from seven power stations, furnishing in all 47,000 amperes. Four of these are situated upon the East River water front and supply over 80 per cent. of the full load current. The currents return to the power-houses by the following paths:

First by the rails of this system, which are all bonded together, different lines employing different bonds. There are, for example, the cast weld bond, showing a conductivity of 100 per cent. or more of continuous rail, the Johnson electric weld bond, showing 85 per cent., the R. P. Brown interfoliated bond giving 94 per cent., and the protected rail bond giving varying conductivities according to size of bond and rail.

The second path of return results from the peculiar geographical position of the borough, and the peculiar conditions of the traffic. All of the car lines lead to the Borough of Manhattan. During the rush hour at 6 P. M., nearly half of the cars in operation at the time are receiving current within a radius of one mile of the Brooklyn end of the Brooklyn Bridge. At this time a large proportion of the currents are returned by way of the East River.

The third path at present takes but a small part of the current, and consists in return feeders connected with the tracks at various points.

The fourth path, which it is the intention of the engineers of the Brooklyn Rapid Transit Co. to utilize extensively along certain lines, has become available as a result of the combination of the elevated railroad interests and the trolley railroad interests. It is, namely, the whole elevated structure. This is also used at present as a return circuit for the currents used in the operation of the few third rail trains which are now upon the elevated lines.

The fifth return path consists of the mains and the service pipes of the municipal water department, the mains and service pipes of the Brooklyn Union Gas Company, the cables of the New York and New Jersey Telephone Company, and the underground tubes of the Edison Electric Illuminating Company.

These returning currents set up differences of potential between all underground conducting objects. The difference in potential between any two given points varies throughout the day, because of variations of the traffic conditions. In a similar manner it varies with the seasons, and is quite different on Sundays from what it is on week days. Furthermore, the potential differences are gradually growing smaller in the average, because of the better conductivity of the Transit company's return circuit. They are also changing because of changes in the distribution of load among the power-houses.

The difference of potential between the rails and the hydrants and the rails and the gas mains varies from a fraction of a volt to 25 volts. Between the two ends of the Brooklyn Bridge there has been a difference of potential of 20 volts. Each power-house is surrounded by equipotential curves, and in the immediate vicinity of each the fall of potential is quite rapid.

The city may be divided up into districts, each power-house drawing current from a district. The boundaries of these districts hold the same position towards the returning currents of electricity as mountains do towards the water of a watershed. The difference of potential between a point on the boundary of a district and the ground in the immediate vicinity of the power-house supplying that district has been found to reach as high a value as 40 volts.

The municipal water mains pass through nearly all streets of the city and vary in size from 48 inches in diameter down. They are all made of cast iron. Some are known as Scotch cast iron pipes. These were made in Scotland and are of a peculiarly

hard and tough cast iron, which exhibits a very white surface on fracture, indicating a combination of the contained carbon. These pipes can always be recognized by ribs which occur at every two feet along the surface, and which are about four inches wide. These ribs consist of a thickening of the metal intended to furnish a firmer seating and more perfect joint for taps and branches.

Other mains are of American manufacture, are very much softer than the Scotch iron, but also exhibit a white surface on fracture. The employees of the water department prefer to work upon these mains because of the much less labor required to operate the cutting tools, owing to the relatively greater softness. In no case has an electrolytic corrosion of the water mains been discovered in the city, although many cases of corrosion of the service pipes have occurred.

The Brooklyn Union Gas Company has 755¼ miles of gas mains. These are all made of white cast iron. From them are led wrought iron service mains which are supplied with malleable iron and in some cases brass fittings. There are 272 miles of wrought iron service pipes. These with their fittings have suffered corrosion in very many cases. Thirty-eight service pipes on one block were completely destroyed in three years. However, not until within a year has any corrosion of the mains been discovered, and then in but two cases. In each case the main was in an excessively dangerous district.

The gas company claims that there has been an abnormal increase of leakage since the introduction of electric traction in 1892. The leakages for various years are not accessible, but during 1899 it amounted to 13 per cent. of the total production of 4,500,000,000 cubic feet.

The New York and New Jersey Telephone Company has many miles of underground cables, the lead coverings of which have been pitted and perforated in many cases by electrolysis. The company, however, is fully aware of the possibilities of electrolytic corrosion, keeps itself informed of its cables, and concerning the stray currents in their sheathings.

The Edison Illuminating Company has over 100 miles of underground tubing. These tubes have suffered considerably from electrolytic corrosion, doubtless resulting in many cases in the short-circuiting of the enclosed conductors.

Considering the magnitude of the system of the Rapid Transit Company, considering the time that it has been in operation (the

first electric car was operated in 1892), considering the poorness of the ground return which existed on parts of the system up to within three or four years, it is surprising that no evidences of the corrosion of cast iron have been discovered with the exception of the two cases mentioned above.

The apparent immunity of cast iron was noticed by the Board of Commissioners of Electric Subways of the City of Brooklyn, and attention was called to the fact in several of their reports. These reports indicate that in their opinion the immunity was due to the peculiar chemical constitutions of the special kinds of cast iron of which the mains were constructed. It hardly seems credible that such a form of iron could exist.

To experimentally test the matter, samples of Scotch and American pipes have been obtained from the water department as well as samples of the gas mains from the gas company. These have been used as anodes in various electrolytic cells. The electrolytes consisted of samples of earth from various parts of the city, moistened in some cases with distilled water, and in other cases by hydrant water or salt water. These cells were subjected to voltages of various magnitudes. In every case the anode was corroded, showing conclusively that there is no immunity because of chemical constitution.

In preparing some experiments to determine whether or not the apparent immunity of cast iron mains was due to an electrolytic polarization E. M. F., due to absorbed gases in the pores of the rough exterior of the pipes and of sufficient magnitude to prevent the sending of any considerable current by the stray voltages, the true cause of immunity was discovered. In the casting of pipes in sand molds, the hot iron unites with a layer of the sand to form a silicious compound probably silicate of iron which forms a thin coating over the surface of the completed pipe. This coating is extremely thin, and is a non-conductor of electricity. It is not continuous, but contains perforations in many places. If a piece of pipe be covered with insulating paint, exposing only the rough sand-pocked exterior surface, and if it be made an anode in an electrolytic solution, much less current will flow through the solution under a given impressed E. M. F. than under similar conditions with an anode exposing a filed surface of equal area. In some cases, no current at all will pass until the impressed voltage rises to a certain minimum value. If, however, a current be made to pass for a few moments under a

moderately high impressed E. M. F., the rough sand-pocked surface becomes conducting throughout. The protecting film or skin seems to act like the non-conducting film thrown down in an aluminium cell. The existence of a perforated skin can also be shown by endeavoring to close a circuit, which contains a current indicating device, by means of a wire on the sand-pocked surface. The end of the wire may be rubbed around in many places before there is any indication of a closed circuit. Then, again, a spot will be found where the circuit is closed, and there is no indication of resistance of any magnitude at the point of contact.

There is another thing which is perhaps equally as influential in preventing electrolytic corrosion, and that is the resistance offered by the soil. The various interested companies have observers in the field recording the potential differences between the rails and their underground system. Whenever the system is positive to the rail, the district is considered as dangerous, and corrosion is expected. It is well to notice that as corrosion will result at one side of any discontinuity of a metallic circuit, it may be expected to occur even in districts which are not considered dangerous. On the other hand, the amount of corrosion which will take place in a dangerous district under a given potential difference is dependent upon the smallness of the resistance offered by the soil. Now the measurement of the resistance of soil under laboratory conditions gives information which can hardly be applied with propriety to street conditions. It is much to be preferred that the resistance between the tracks and the other systems should be measured directly. While it is impossible to determine the resistance in such a manner as would enable one to calculate the current density at any point, and to ascertain the direction of flow lines, yet some idea of the magnitude of the ground resistance can be determined in the following method, which makes use of a low reading voltmeter (0 to 3 volts), and a battery having an E. M. F. of E volts. Let the resistance of the voltmeter be R ohms; then at any reading of the voltmeter θ, the current which is traversing that voltmeter is θ/R amperes. Now to measure the resistance between two points, for example, a point on a rail and a point on a hydrant, take the following three readings:—E', with the voltmeter alone connected between the two points; E with the battery alone connected to the voltmeter, and θ with the battery and voltmeter connected in series between the

two points. The effective resistance X between the two points is determined by considering that

$$\frac{E \pm E'}{R + X} = \frac{\theta}{R}$$

whence

$$X = \frac{(E \pm E')\, R}{\theta} - R$$

$$= R \left(\frac{E \pm E'}{\theta} - 1 \right).$$

For ground voltages, which are less than one volt, two cells of ordinary dry battery are sufficient. The assumption is made that the small current sent by the battery in making the measurement does not produce an E. M. F. of polarization of appreciable magnitude. This is unquestionably warranted when we consider the exposed area of the pipe or rail, and the smallness of the current. Measurements of effective resistance taken at a great many points between the hydrants of the water system and the rails in Brooklyn give values lying in the majority of cases between 10 and 35 ohms. The character of pavements seems to have no great influence on the resistance of the soil underneath. Measurements have been made in the case of asphalt, cobble stone, Belgian block, granite block, vitrified brick, and dirt roads. In all cases there were variations in resistance with different conditions under the same pavements, but the average resistance was nearly the same in all cases.

It is very probable that the current which would flow through the resistance indicated by these measurements under a given difference of potential would be distributed over a large area of pipe surface, and therefore the current density under voltages of the magnitude of those which exist in Brooklyn, would require a long time to result in destructive corrosion.

These investigations have been carried out in collaboration with Mr. Charles V. Rapelje.

A paper presented at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 18th, 1900. President Hering in the Chair.

A PRACTICAL TRANSMITTER USING THE SINE WAVE FOR CABLE TELEGRAPHY; AND MEASUREMENTS WITH ALTERNATING CURRENTS UPON AN ATLANTIC CABLE.

BY ALBERT C. CREHORE, PH. D. AND GEORGE O. SQUIER, PH. D.

This paper describes a method of utilizing the sine wave of electromotive force for cable signaling, and a practical cable transmitter employing these principles. The employment of a sine wave electromotive force makes available the ordinary methods of measurement such as are used on power transmission lines, and some results are given of such measurements upon submarine cables.

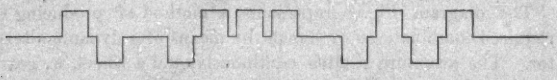


FIG. 1.—Letters A, B and C. Battery form of electromotive force wave.

The present method of operating long cables employs a primary battery as the source of power, and a siphon recorder to record the signals. In this system a dot is transmitted by a positive current obtained by connecting one pole of the battery to the cable and the other to the earth, and a dash by a negative current connecting the opposite pole to the cable, the time required for a dot and a dash being the same.

Several letters of the alphabet require two or more consecutive signals in the same direction, and in order to separate these successive signals at the receiver it is usual to connect the cable to earth during the latter portion of each individual signal. The electromotive force employed in transmitting the letters A, B and C, is shown in Fig. 1, where it is seen that the cable is directly connected to earth during one-fourth of each signal. This rep-

resents the form of electromotive force as furnished by the battery and transmitter, and if no condensers were used would be the form of wave applied to the cable; but it is usual to employ condensers at each end of the cable whether working simplex or duplex, and these condensers greatly modify the shape of the electromotive force which is applied to the cable itself as will be shown later.

It is important in designing a sine wave transmitter to make an instrument which transmits to the cable the same combinations of impulses as those at present employed in cable signaling, so that as far as the receiving station is concerned there is no change whatever required either in instruments or technical staff. The difference between the ordinary and the sine wave method is in the shape of the electromotive force employed for each individual signal at the transmitting end of the cable. In the sine wave system instead of the square topped form shown in Fig. 1 each signal consists of a single sinus or semi-wave of alternating current, as represented in Fig. 2.

FIG. 2.—Letters A, B and C. Sine wave electromotive force.

The diagram Fig. 3 represents a method of producing the required combinations of signals by means of a dynamo alternator. The armature rotates continously, and a wheel, W, geared to the alternator shaft feeds the paper tape, T, in synchronism with the electromotive force generated, so that one semi-wave of electromotive force is generated during the time that the tape is advancing a distance equal to the distance between the centers of two consecutive feed holes. The transmitting tape is similar to the ordinary tape, having a row of perforations on one side of the feed holes to transmit dots, and on the other side for dashes. Brushes are employed for making contact through these perforations, and by making the holes a proper size the duration of contact can be made equal to the whole or any portion of the semicycle desired. The two brushes for transmitting the signals are on the same line transversely across the tape, and each brush is connected to one terminal of the armature winding through a divided ring, A, which causes pulsations of electromotive force to be supplied to the transmitter brushes P and Q consisting of successive semi-sinuses in the same direction A

continuous ring, B, is also supplied which connects the middle of the armature winding to line. The contact s upon which the

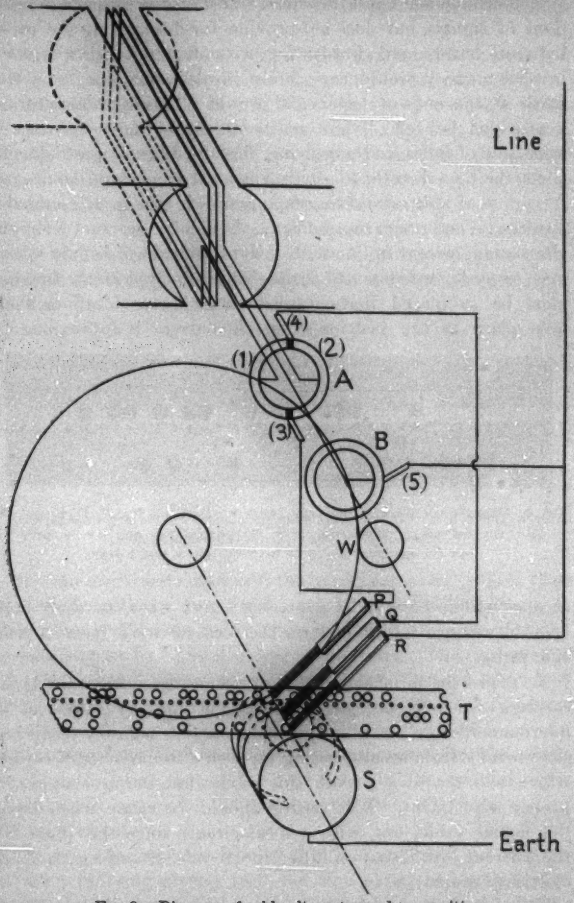


FIG. 3.—Diagram of cable alternator and transmitter.

three brushes P, Q, and R bear is connected to the earth or return. Thus it appears that whenever contact is established on the dot side of the tape between P and S a positive sinus is trans-

mitted to line, and contact between Q and S on the dash side sends a negative sinus.

The arrangement just described transmits the proper combinations of signals, but does not provide for discharging the cable between letters and words; for without the brush R the two brushes P and Q would completely insulate the line from the earth at the ends of letters and words. This earth connection is provided between letters and words by adding to the tape a third row of holes and supplying the third brush R which connects the line directly to earth whenever a perforation occurs. A sample of the transmitting tape is shown in Fig. 4. where the letters A, B and C are represented. Evidently to send a simple alternating current to line with this transmitter it is only necessary to perforate dots and dashes successively, but the brushes must be so placed that contact through the perforations shall take place at the instants when the current is approximately

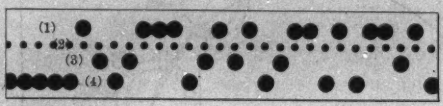


FIG. 4.—Sample of transmitting tape, showing letters A, B, C, D, E and F. (1) is the dot row, (2) the feeding row, (3) the dash row and (4) the space row for earthing the cable between letters and words.

zero, as will be more fully explained later; otherwise there will be a disturbance which distorts the form of wave from its true sine form.

To adjust the brushes easily they are mounted upon the same carriage which is adjustable along the tape by means of a micrometer screw. This adjustment may be made by receiving the current from an alternating tape on a local siphon recorder which will record a smooth sine wave when the brushes are in proper adjustment. This setting should be made when using the actual cable, not with a local circuit, since the phase of the current is different on different circuits, according to their electrical properties.

The three-hole tape is prepared on a perforator which differs from the ordinary form only in the arrangement of the punches.

The operator can detect no difference between its action and that of the ordinary perforator. With a slight change the ordinary perforator can be adapted so as to prepare the three hole tape.

One peculiarity met in designing a dynamo alternator for working long cables is the low frequency required, which for an Atlantic cable is as low as three or four per second, while the ordinary frequencies of alternators for lighting and power circuits vary from 25 to 150 per second. A means of increasing the frequency is to increase the number of poles of the machine, but if the object is to decrease the frequency in this way the number of poles cannot be less than two. One revolution of an armature in a two pole field gives a complete cycle of electromotive force which limits the speed of the armature to three or four revolutions per second.

FIG. 5.—Oscillograph record of alternating electromotive force obtained from a shuttle wound armature in a two-pole field.

In the armatures designed, the reactance even at these low frequencies rather than the resistance, is the controlling factor in determining the short-circuit current, and is so great that the armatures may be short-circuited at any time. The inductance of the whole armature is four times that of the half armature, as the two halves are identical, and the mutual induction between the halves is equal to the self-induction of one half. Since the electromotive force generated by the whole armature is twice that of the half armature, it results that the short-circuit current of the whole armature is only half that of the half armature.

An armature was constructed shuttle wound and gave a form of wave differing greatly from the sine wave, the electromotive force being shown in Fig. 5 as determined photographically by an oscillograph. Drum-wound armatures were made which give very accurate sine waves as shown by oscillograph records. As

will be presently explained, experiment showed a superiority in favor of the sine wave form. Fig. 6 shows a practical sine wave cable transmitter and generator.

The cable upon which these preliminary experiments were conducted is known as the "Coney Island" cable, belonging to the Commercial Cable Co., and extends from New York City, U. S. A., to Canso, Nova Scotia, having a length of 880 knots. This cable was laid in 1884, and consists of several sections of two different kinds of cable. Its total ohmic resistance is 13,700 ohms, and total static capacity 231.4 microfarads at 75° F. The two kinds of cable used are known as type "D" and type "E," each having 70 pounds of copper per knot. Type "D" has 115 pounds and type "E" 85 pounds of gutta percha per knot.

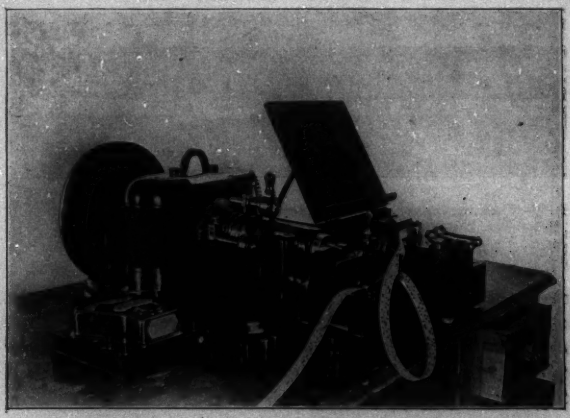


FIG. 6.—Cable alternator, transmitter and perforator.

Beginning at New York, the sections of the cable were approximately as follows:

New York,	Type "E"	127.7 knots.
	Type "D"	612.4 "
Canso.	Type "E"	140.5 "
	Total	880.6

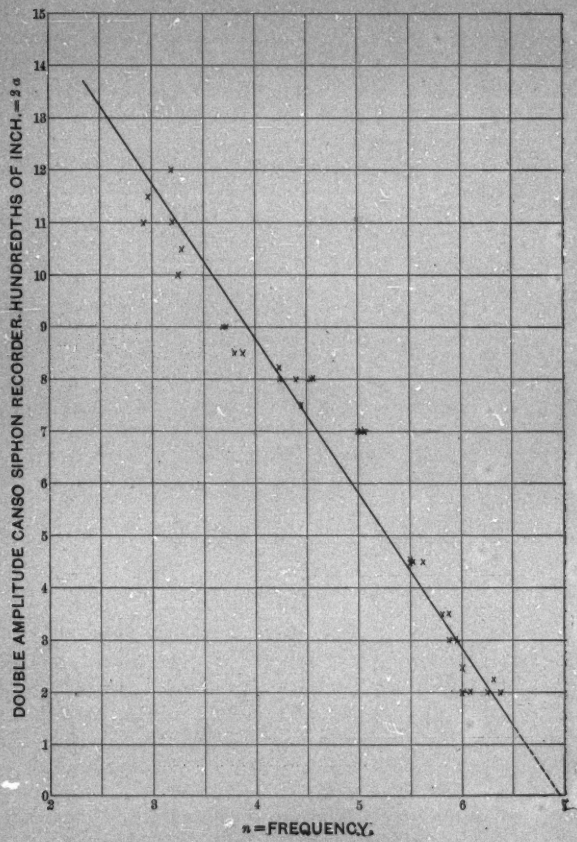


FIG. 7.—Relation between frequency and double amplitude of the receiving recorder with 30 virtual volts impressed at the transmitting end. C. I. cable simplex without condenser at transmitting end, and regular duplex with 50 microfarad condensers at receiving end.

This cable is ordinarily used with duplex working, but for the following experiment the cable was employed simplex without condensers at the sending end, which was New York, and with the regular duplex arrangement for receiving with condensers at Nova Scotia. The siphon recorder in Canso was adjusted in its normal working condition and not changed throughout the experiment.

Volts constant. Frequency and amplitude variable.—A sim-

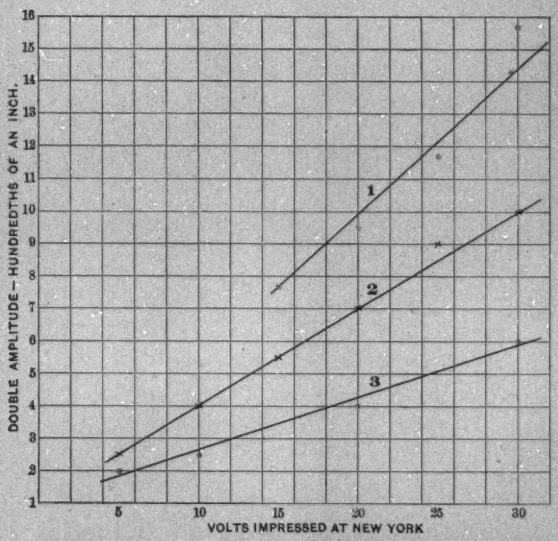


FIG. 8.—Relation between the impressed volts and the double amplitude of the received recorder. (1) Frequency equals 3.05, (2) 4.70, (3) 5.60. C. I. cable simplex without condenser at transmitting end, and regular duplex with 50 microfarad condensers at receiving end.

ple alternating current, having an electromotive force wave like that in Fig. 5, was sent into the cable at constant voltage, and the frequency alone varied between the limits 3 and 6.4 waves per second. The record upon the Canso recorder showed a smooth wave approximating a sine wave, and the amplitudes of

these waves were measured for the different frequencies, giving the result exhibited in Fig. 7. It is seen that the observed points lie within the limits of error almost upon a line whose equation is

$$2a = -2.97n + 20.64$$

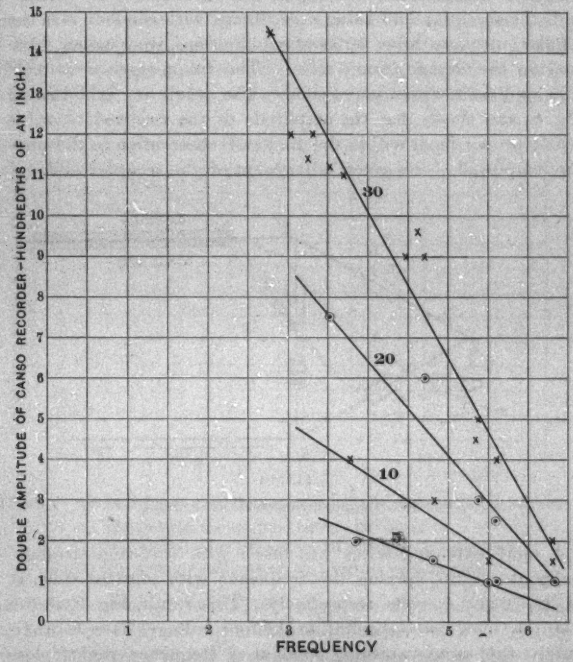


FIG. 9.—Relation between frequency and double amplitude of the receiving recorder for 30, 20, 10 and 5 volts. Circuits the same as in Fig. 7.

where a is the amplitude of the recorder and n the frequency. The pressure was constant throughout at 30 virtual volts. As the frequency increases the amplitude of the distant recorder decreases steadily towards a vanishing point approximately 7 waves per second. With this voltage and recorder adjustment

it could not, therefore, be hoped to send signals with a greater frequency than 7—that is, at a greater speed than 227 letters per minute. One average letter with its space is taken as requiring exactly 3.7 semi-waves.

Frequency constant. Volts and amplitude variable:—To determine the effect of varying the voltage applied to the cable simplex without condensers upon the recorder at the distant end, the receiving end being used duplex with condensers in the regular manner, three series of observations were taken, each varying the voltage from 0 to 30. The frequencies were 3.05, 4.70 and 5.60 waves per second. The result is exhibited in Fig. 8, and shows that the amplitude of the received record is nearly proportional within the limits of observation to the pressure employed, for a given adjustment of the recorder coil.

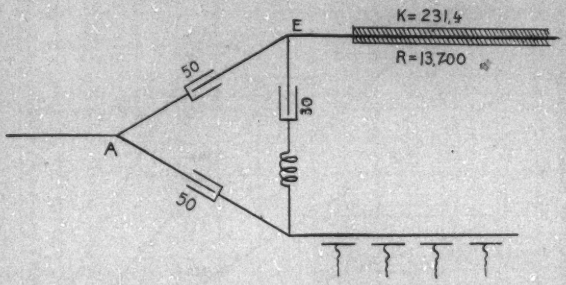


FIG. 10.—Duplex arrangement C. I. cable.

A more extended series was taken with the same arrangements of circuits, varying the frequency with constant volts, at 30, 20, 10 and 5 volts respectively. This result, Fig. 9, shows that the lines corresponding to the four voltages have approximately the same vanishing point at a frequency slightly less than 7.

To make a comparison between the automatic battery transmitter of the Cuttriss pattern, as used by the Commercial Cable Co. and the dynamo alternator, observations were taken with each instrument under the same conditions of the circuit, the recorder having the same adjustment in each case, beginning at low frequencies and increasing beyond the limits of legibility. The cable was used as in regular working, with the duplex

arrangement. The results previously described in Figs. 7, 8 and 9 were obtained with no condensers at the sending end and regular duplex at the receiving end.

The arrangements of circuits and the values of the condensers employed are shown in Fig. 10 and the results in Fig. 11. Curve (1) represents the relation between the double amplitude of the record in Canso and the frequency of the battery reversals sent into the cable at New York, the battery employed being Fuller primary cells, which measured 36 volts on open circuit. With this voltage it is seen that the double amplitude of the excursions of the siphon were about 11/100 inch at a frequency

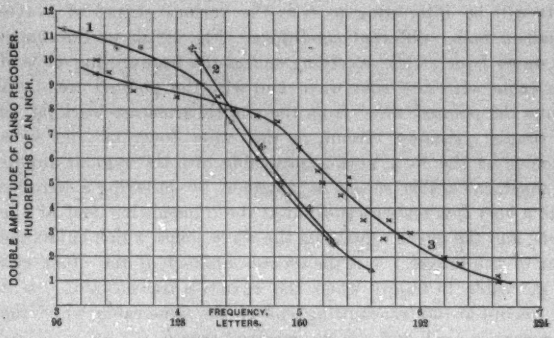


FIG. 11.

Relation between frequency and the double amplitude of the receiving recorder.

(1) The Cuttriss transmitter; battery 36 volts.
(2) The pointed wave alternator; 30 virtual volts upon apex.
(3) The sine wave alternator; 34.1 virtual volts on apex.

of 3 and decreased to 1.5/100 when the frequency increased to 5.6. Curve (2) represents the result obtained with the shuttle-wound armature, which gave a wave represented in Fig. 5, and which was used in the experiments previously described. The pressure employed was 30 virtual volts between the apex of the bridge, *A*, and earth, *E*, Fig. 10. The observations did not extend through so great a range as that with the battery transmitter, and the volts were not the same, but the general shape of the curve is seen to correspond quite closely with the curve (1) throughout the range. It must be remembered that the previous experiments have shown that the ordinates of

this curve (2) are approximately proportional to the voltage employed, so that it may easily be corrected to correspond to any desired voltage. Observations were also taken with a transmitter, furnishing a true sine wave under the same conditions, and the result is given in curve (3). There is a marked difference in the shape of the curve obtained with the sine wave from either of the other curves with the battery or the pointed wave alternator. At the low frequencies the sine wave gives smaller amplitude, and at the high frequencies larger amplitude than the other waves, the curves crossing each other at a frequency between 4 and 5. The pressure for curve (3) was 34.1 virtual volts at a point 75 ohms from the apex.

It will be interesting to note the various shapes of waves obtained under different conditions. Fig. 12 shows the shapes of waves both at the receiving and at the transmitting ends of the cable with the sine wave and with the pointed wave. A shows the pointed wave from the shuttle armature working on a simple resistance circuit, B the wave form of the same machine on the New York-Canso cable with the regular duplex arrangement. The record is obtained by inserting a recorder with a very low resistance shunt at the transmitting end of the cable, and the curve represents the wave shape which enters the apex of the bridge. C is the record obtained at the other end of the cable in Canso when the wave B is transmitted. D is the record at the transmitting end of the same cable when the sine wave is used, and E is the received record.

Battery reversals give curves just as nearly sine waves at the distant end as either C or E.

It appears therefore that approximate sine waves are received at the distant end of a long cable no matter what the shape of the alternating current transmitted.

Current and Phase Measurements.

The object of the following measurements was to obtain the law of variation of current and phase in the transmitting end of a cable with the frequency. To make these measurements a special set of apparatus was designed which included a switchboard so constructed that current and potential could quickly be read from the same instrument, since the time when the cable was available was limited. The measuring ammeter was a special one made by the Weston Instrument Co. consisting of one coil sus-

REPRODUCED FROM SIPHON RECORDS.

Actual size.

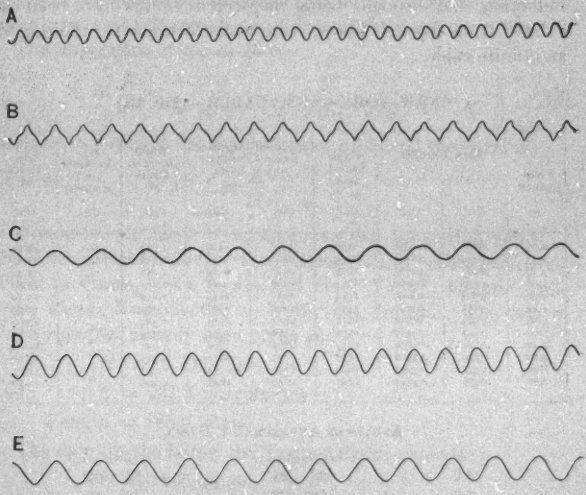


FIG. 12.

A. Pointed wave on local resistance.
B. Pointed wave in apex of C. I. cable, transmitting end.
C. Record of B at receiving end.
D. Sine wave in apex of C. I. cable, transmitting end.
E. Record of D at receiving end.

pended within a stationary coil as in the regular voltmeter, but the whole was immersed in oil to prevent the oscillations of the needle which occur when measuring such low frequencies. With this apparatus the current in the apex of the bridge was measured at various frequencies, the constant pressure at a point 75 ohms from the apex being 34.1 virtual volts, and the results obtained are shown in the table Fig. 13.

To compare these results with theory in the case of long submarine cables having resistance and distributed capacity, self-induction and leakage being neglected, curves have been calculated from the well known sine wave formula for the case of an infinite cable.

NEW YORK-CANSO CABLE.—(FIG. 13.)

Frequency.	Apex Current.		Cable Impedance.	Resultant Impedance Cable Condenser and 75 ohms.		Ratio Apex to Cable E. M. F.	E_3 At Apex + 75 ohms.	E_1 Cable E. M. F.
n	*Obs.*	*Cal.*	*Cal.*	*Obs.*	*Cal.*	*Cal.*	*Obs.*	*Cal.*
2.00	.0196	.01920	2162	3480	3556	1.613	34.1	20.75
2.33	.0229	.02145	2005	2980	3180	1.553	"	21.53
3.33	.0269	.02705	1676	2540	2590	1.458	"	22.72
4.08	.0302	.03080	1514	2260	2218	1.412	"	23.20
4.08	.0308	.03080	1514	2216	2218	1.419	"	23.20
4.42	.0325	.03240	1455	2100	2106	1.393	"	23.55
4.66	.0341	.03340	1418	2000	2042	1.382	"	23.66
5.00	.0347	.03485	1370	1966	1957	1.370	"	23.83
5.42	.0364	.03650	1313	1874	1868	1.357	"	24.00
5.66	.0372	.03762	1287	1833	1812	1.345	"	24.20
6.00	.0392	.03895	1250	1740	1752	1.333	"	24.33
6.66	.0418	.04145	1180	1630	1648	1.320	"	24.50

ANGLES OF ADVANCE C. I. CABLE.

n	Computed.	Observed.
3.2	58° 24′	55° 05′
4.0	56° 8′	49° 16′
5.0	55° 8′	44° 25′
5.66	54° 12′	48° 08′

$$i = E\sqrt{\frac{C\omega}{R}}\,\varepsilon^{-x\sqrt{\frac{CR\omega}{2}}}\,\sin\left\{\omega t - x\sqrt{\frac{CR\omega}{2}} + \frac{\pi}{4}\right\} \qquad (1)$$

In this equation i represents the instantaneous value of the current at any point of the cable at a distance x from the origin and a time t. E is the maximum value of electromotive force applied to the cable. ε is the Naperian base. R is the resist-

ance and C the capacity of the cable per unit length. ω is 2π times the frequency.

For quantities measured at the transmitting end of the cable x is zero, and equation (1) reduces to

$$i = E\sqrt{\frac{C\omega}{R}} \sin\left\{\omega t + \frac{\pi}{4}\right\}$$

or
$$i = I \sin [\omega t + \theta] \qquad (2)$$

where I is the maximum current, and θ is the angle by which the current leads the electromotive force. This angle is constant equal to 45 degrees independent of the frequency.

The impedance of the cable is:—

$$Z_1 = \frac{E}{I} = \sqrt{\frac{R}{C\omega}} = \sqrt{\frac{R}{2\pi C}}\sqrt{\frac{1}{n}} = c_1\sqrt{\frac{1}{n}} \qquad (3)$$

where c_1 is constant for any particular cable and the current:

$$I = \frac{E}{Z_1} = \frac{E}{c_1}\sqrt{n} \qquad (4)$$

Measurements have been taken on two submarine cables of the Commercial Cable Co., the "Coney Island" cable from New York to Canso, Nova Scotia, and the "No. 3" Atlantic cable from Canso, Nova Scotia, to Waterville, Ireland. The data of the former has already been given and is:

$R = 13{,}700$ ohms

and $C = 231.4$ microfarads

Length $= 880.6$ knots.

The data for the latter, the Trans-Atlantic cable is:

$R = 4895$ ohms

and $C = 914$ microfarads.

Length $= 2164$ knots.

By substitution in (3) and (4) we have for the "C. I." cable

$$Z_1 = \frac{3060}{\sqrt{n}} \text{ and } I = \frac{E}{3060}\sqrt{n} \qquad (5)$$

and for the "No. 3" Atlantic cable

$$Z_1 = \frac{925}{\sqrt{n}} \text{ and } I = \frac{E}{925}\sqrt{n} \qquad (6)$$

(7) With 30 volts on No. 3 $I = .03245\sqrt{n}$

(8) With 40 volts on No. 3 $I = .04335\sqrt{n}$

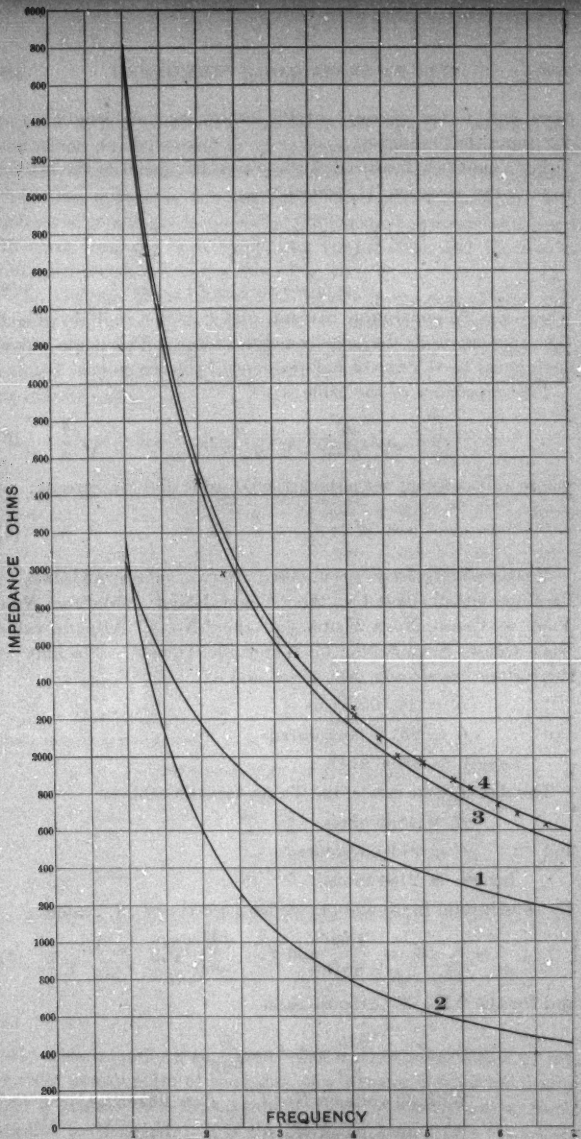


FIG. 14.—C. I. Cable.

(1) Calculated impedance of cable.
(2) Calculated impedance of 50 mf. condenser.
(3) Calculated resultant impedance from apex.

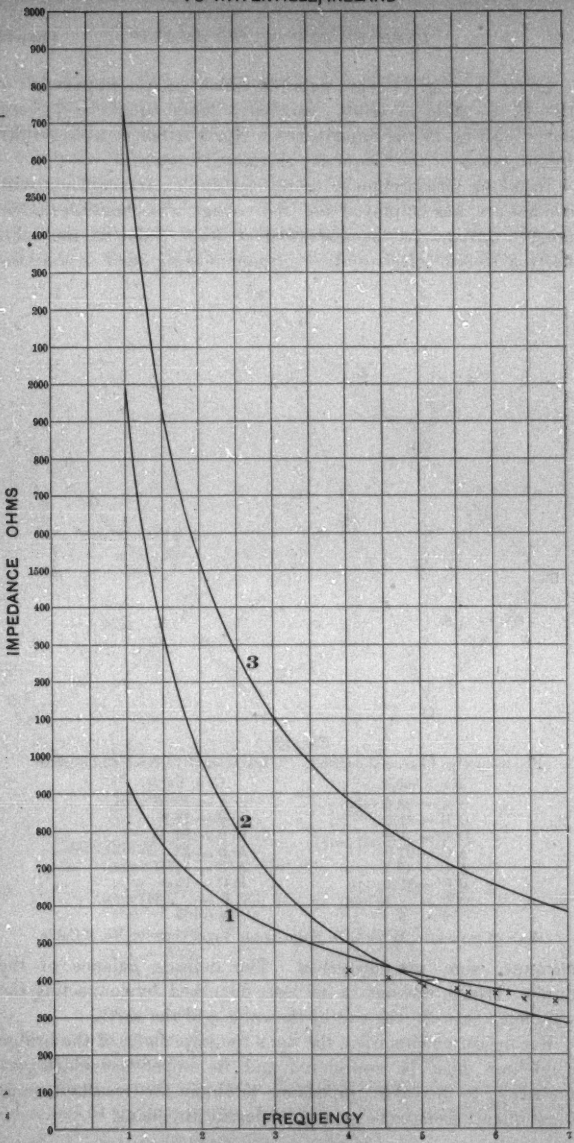


FIG. 15.—No. 3 Atlantic Cable.

(1) Calculated impedance of cable.
(2) Calculated impedance of 80 mf. condenser.

Curve (1) Fig. 14 represents the values of the impedance of the C. I. cable in ohms, calculated from equation (5), and curve (1) Fig. 15 the impedance of No. 3 Atlantic cable for different values of the frequency calculated from (6).

In taking measurements the regular duplex arrangement with condensers was employed and the voltage was sometimes maintained constant on the apex, and at other times on the cable itself, a Kelvin electrostatic voltmeter being used so that the

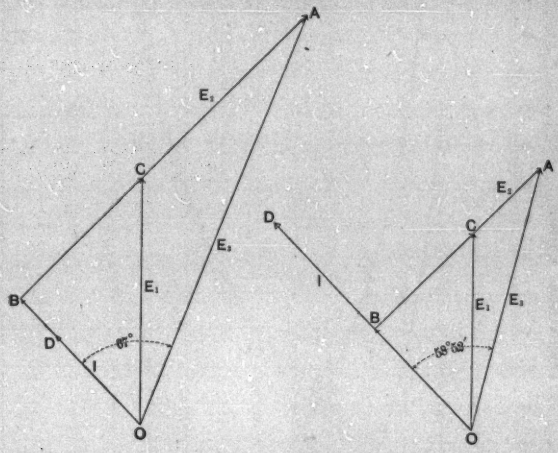


FIG. 16.

Electromotive force and current. No. 3 cable.	Electromotive force and current. C. I. Cable.
O A — 53.6 volts.	O A — 32.68 volts.
O B — 21.2 "	O B — 16.9 "
O C — 30.0 "	O C — 23.83 "
A C — 27.9 "	A B — 28. "
A B — 49.1 volts.	A C — 11.01 volts.
B C — 21.2 "	B C — 16.9 "
O D — .15 amp.	O D — .0347 amp.
n — 5	n — 5

Scale of current O D for C. I. Cable is ten times that for No. 3 Cable.

currents were not disturbed. The delicate balance of the duplex bridge was not in the least disturbed by connecting the voltmeter between the end of the cable and the earth.

For measurements upon the apex the impedance of the bridge condenser must be considered, and its impedance added geometrically to the cable impedance to obtain the resultant, since these quantities have in general different directions.

The line oc, Fig. 16, represents the electromotive force, E, applied to the end of the cable. In advance of this by 45 degrees is the current o 1 in the cable. The electromotive force E, is resolved into two components ob in phase and bc in quadrature with the current, each component being equal to $E/\sqrt{2}$ The electromotive force, E_2, of the bridge condenser is in quadrature with the current, and represented by oa. The electromotive force, E_3, applied at the apex is the sum of these com-

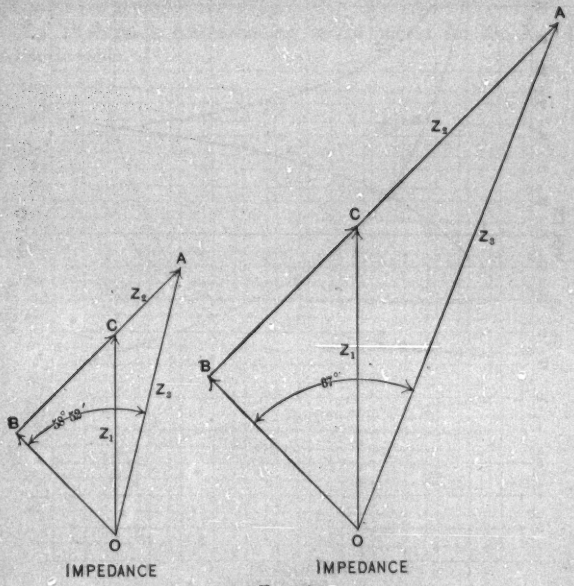


FIG. 17.

C. I. Cable.		No. 3 Cable.	
O A —	187.7 ohms.	O A —	750. ohms.
O B —	969. "	O B —	292.5 "
O C —	1389. "	O C —	414. "
A B —	1605. "	A C —	398. "
A C —	636. "	A B —	690.5 "
B C —	969. "	B C —	292.5 "
n —	5.	n —	5.

ponents represented by oa. If oc the electromotive force on the cable is constant, then oa the electromotive force at the apex decreases as the frequency increases. The impedance diagrams

Fig. 17 are obtained by dividing each line of the electromotive force diagrams by the current, and they are similar figures.

Fig. 18 represents electromotive forces calculated for the C. I. cable with 50 microfarad condensers. The line (1) represents

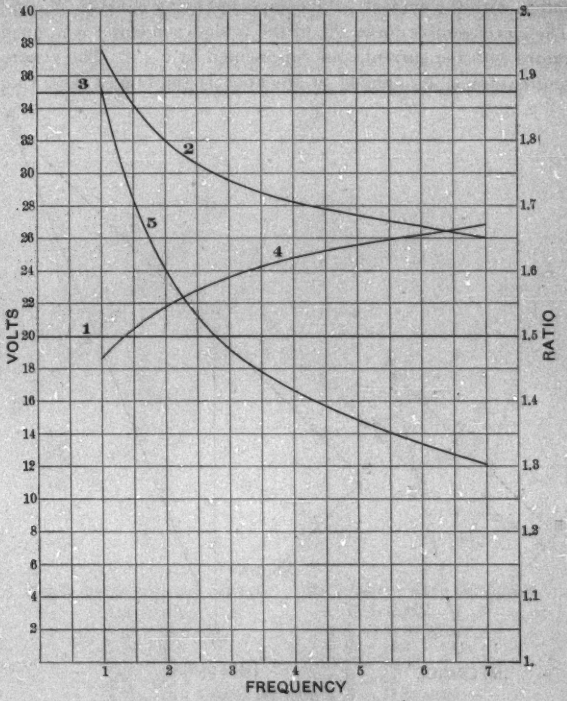


Fig. 18.—C. I. Cable.

(1) Twenty virtual volts on cable.
(2) Virtual volts required upon apex to produce 20 volts constant on cable.
(3) Thirty-five virtual volts at apex.
(4) Virtual volts upon cable due to 35 volts upon apex.
(5) Ratio of apex to cable volts.

20 volts applied to the cable, and is constant for all frequencies. Curve (2) represents the pressure required upon the apex to produce 20 volts constant on the cable; (3) represents 35 volts applied

constantly at the apex, and (4) represents the pressure which would be applied upon the cable as the result of 35 volts constant at the apex of the C. I. cable.

The ratio of the pressure at the apex to that upon the cable is constant for any particular frequency and independent of the pressure.

The values of the ratios of apex to cable volts at different frequencies are given in curve (5).

Fig. 19 shows a corresponding set of curves for the No. 3 Atlantic cable.

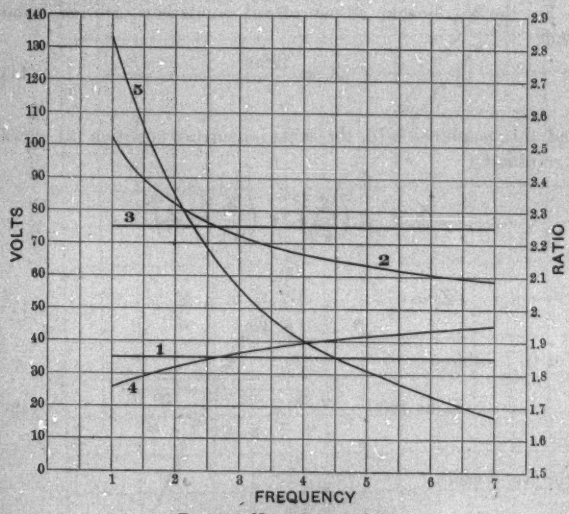


FIG. 19.—No. 3 Atlantic Cable.

(1) Thirty-five virtual volts on cable.
(2) Virtual volts required upon apex to produce 35 volts constant on cable.
(3) Seventy-five virtual volts at apex.
(4) Virtual volts upon cable due to 75 volts upon apex.
(5) Ratio of apex to cable volts.

Figs. 14 and 15 each have two curves (2) and (3) in addition to those described, which represent the calculated impedance of the condenser and the resultant impedance of cable and condenser for the C. I. cable and for No. 3 respectively.

The impedance of the condenser is:

$$Z_2 = \frac{E_2}{I} = \frac{1}{C\omega} = \frac{1}{2\pi C}\frac{1}{n} = \frac{c_2}{n} \tag{9}$$

For the C. I. cable 50 microfarad condensers are employed and

$$Z_2 = \frac{3180}{n} \tag{10}$$

For the No. 3 cable 80 microfarad condensers are employed and

$$Z_2 = \frac{1990}{n} \tag{11}$$

and this, combined with the cable impedance equation (3), gives a resultant,

$$Z_3 = \sqrt{\left(\frac{Z_1}{\sqrt{2}}\right)^2 + \left(\frac{Z_1}{\sqrt{2}} + Z_2\right)^2}$$

$$Z_3 = \sqrt{\frac{c_1^2}{n} + \frac{\sqrt{2}\ c_1\ c_2}{n\ \sqrt{n}} + \frac{c_2^2}{n^2}} \tag{12}$$

For C. I. cable

$$Z_3 = 1000\sqrt{\frac{9.38}{n} + \frac{13.75}{n\ \sqrt{n}} + \frac{10.16}{n^2}} \tag{13}$$

For No. 3 cable

$$Z_3 = 1000\sqrt{\frac{.858}{n} + \frac{2.602}{n\ \sqrt{n}} + \frac{3.96}{n^2}} \tag{14}$$

Fig. 20, curve (1), gives the calculated current in the apex of the C. I. cable for 34.1 volts, applied to the apex. This is calculated by dividing 34.1 by equation (13). Fig. 21 shows two current curves for No. 3 cable, calculated from equations (7) and (8) for 30 and 40 virtual volts constant on the cable itself.

Fig. 22 gives the calculated angles by which the current in the C. I. cable leads the pressure upon the apex for different

frequencies. The pressure upon the cable leads the current by a constant angle of 45° in either cable, and the angle between

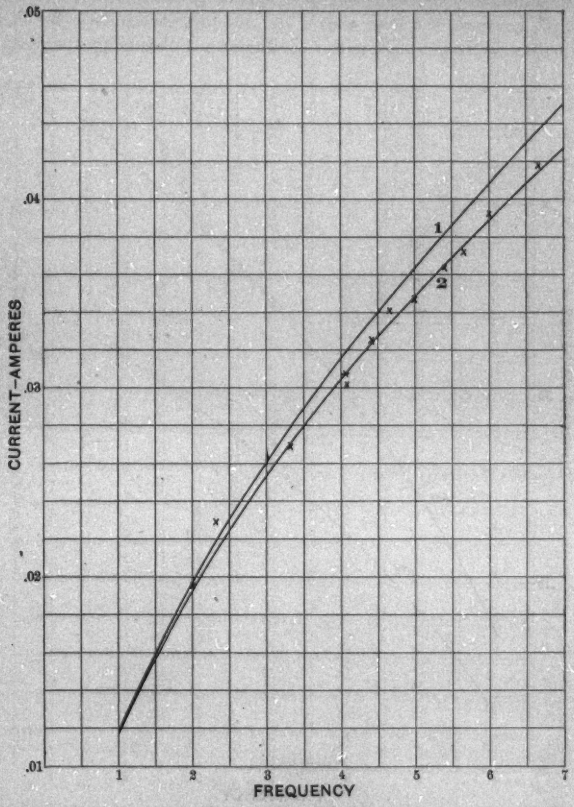


FIG. 20.—C. I. Cable.

(1) Relation between current at the apex and frequency with 34.1 virtual volts impressed at the apex.
(2) Corrected apex current with 34.1 virtual volts constant at a point 75 ohms from the apex.

the pressure upon the cable and upon the apex may be found by subtracting 45° from the ordinates of the curves.

When the measurements in the table 13 were taken on the C. I. cable, the ammeter was in the circuit before the apex, and

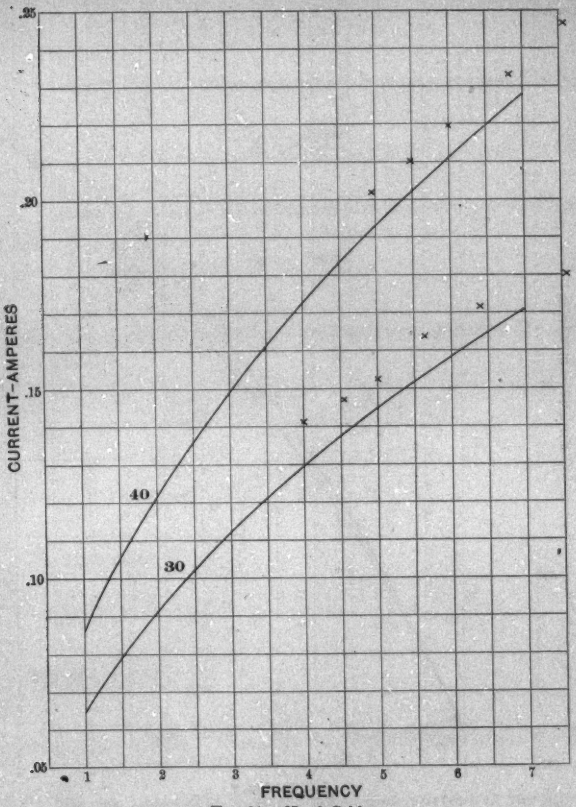


FIG. 21.—No. 3 Cable.

(40) Relation between current in the apex and frequency with 40 virtual volts constant upon the cable.

(30) Same as above, with 30 virtual volts on the cable.

the pressure read by a voltmeter connected not directly to the apex but to the other side of the ammeter, which had a resist-

ance of 75 ohms. The calculated curve (3), Fig. 14, represents the resultant impedance of cable and condenser from the apex. Curve (4) is calculated to represent the impedance including the 75 ohms of the instrument. It is seen that the observed values follow very closely the calculated curve (4). Since the pressure

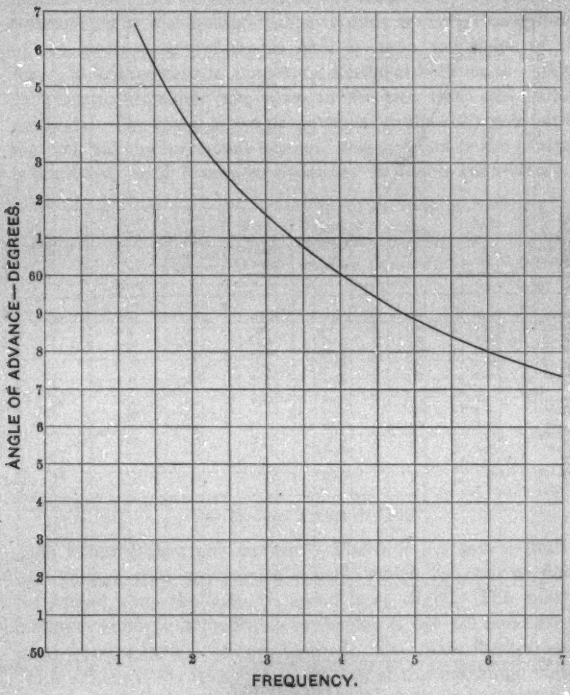


FIG. 23.—C. I. Cable.

Calculated angles between cable current and apex pressure.

was maintained constant at a point 75 ohms from the apex instead of at the apex, curve (2), Fig. 20, has been calculated, and is seen to agree very closely with the current observations.

Measurements were made by the three ammeter method upon the phase difference between the current in the apex of the C. I. cable and the impressed electromotive force. For this

purpose a non-inductive shunt was connected from apex to earth and the current measured in the three circuits thus produced, A the current in the alternator, B in the apex of the bridge and C in the shunt. The resistance of the ammeter thus inserted was 75 ohms between the apex and the terminal of the shunt, which fact modifies the angle of phase between the current and elec-

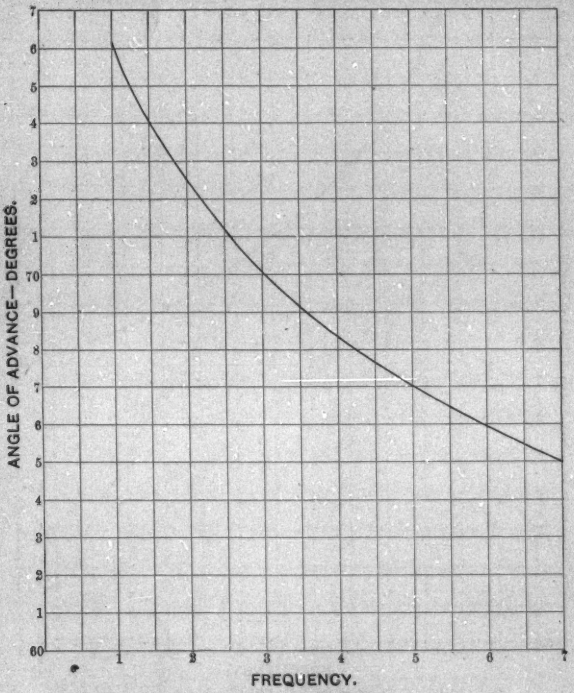


FIG. 23.—No. 3 Atlantic Cable.

Calculated angles between cable current and apex pressure.

tromotive force at the apex. Allowance has been made for this resistance in the calculated values as seen in the table Fig. 13.

The measurements upon No. 3 Atlantic cable are given in the table Fig. 24, and they are also seen upon the curves in Figs. 15 and 21. The agreement is not as close as in the case of the C. I. cable.

On the Comparison between Electromotive Forces Employed in the Sine Wave and the Ordinary Battery Method of Cable Signaling, and on the Interpretation of the Term "Equivalent Voltage."

Since the speed of signaling or the number of letters per minute which can be transmitted and received by a given set of instruments on a submarine cable depends upon the magnitude of the electromotive force as well as upon the shape of the wave, it is important to note the differences between the physical phenomena which take place in the sine wave and battery methods. The speed is not proportional to the voltage by either method, but the increment becomes less and less as the pressure is increased, until it may be necessary to double the voltage to

Cable E. M. F. E.	n	Apex Current Amperes Observed.	Apex Current Amperes Calculated.	Cable Impedance Z. Observed.	Cable Impedance Z. Calculated.	Ratio Apex to Cable E. M. F. Calculated	Apex E. M. F. Calculated
30	4.00	.141	.1286	425.5	466	1.000	57.0
	4.55	.147	.1401	408.1	436	1.845	53.4
	5.03	.151	.1450	397.5	422	1.806	54.1
	5.63	.164	.1540	365.9	389	1.761	52.9
	6.40	.172	.1637	348.8	367	1.705	51.15
	7.58	.180	.1770	333.3	335	1.635	49.0
40	4.96	.202	.1926	396 0	415	1.811	72.5
	5.48	.211	.2021	379.2	396	1.771	70.95
	6.00	.220	.2116	363.6	378	1.735	69.45
	6.82	.234	.2238	341.9	354	1.671	66.95
	7.58	.247	.2361	323.9	335	1.635	65.45
53	6.17	.290	.2842	365.5	372	1.722	91.3

Fig. 24.—No. 8 Atlantic Cable.

gain a few letters per minute. There is a practical limit to the voltage with any particular cable which it is not profitable to exceed, since the gain in speed is so slight. The limit of voltage which it is profitable to employ is not the same for the sine wave as for the battery method. To obtain the best speed with either system it should be worked at this maximum voltage point, which limit can only be determined by experiment. Before such a limit is reached, however, there are often other causes which prevent the best voltage from being employed. If a fault develops, a high potential at that point might effect the complete interruption of the cable. When the fault is discovered, it is customary to reduce the voltage to prevent entire interruption. There is at present such a fear of employing high voltage on submarine cables that a limit is set to the pressure at which cables may be operated, and this limit, for most of the cables of the

world, is little more than 50 volts. Modern cables are subjected to a pressure of 5,000 volts alternating while in the cable tanks for a period often as great as half an hour. Thus the voltage at which the cable is tested is 100 times as great as that actually employed in signaling. The insulating material of an uninjured cable will withstand as high pressures as will ever be desired in signaling, but no factory test can guarantee the cable from mechanical injury after it is laid.

Since the voltage is limited upon a cable, it is evident that the system which can furnish the higher speed at the same pressure

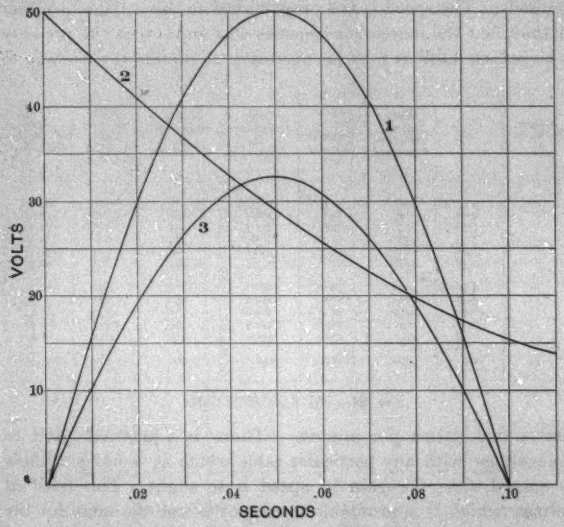


FIG. 25.—(1) Sine wave and (2) battery wave having the same maximum (3) Fundamental term or effective component of battery wave 2.

has the advantage, or that system which can furnish a given working speed with the lowest voltage is safest to employ.

The true definition of equivalent voltage from this standpoint would then be such pressures as would equally strain the insulating material of which the cable is constructed.

The breaking strain of an insulating material not only depends upon the pressure to which it is subjected, but upon the time during which that pressure is applied. It is well-known that the dielectric of a condenser may break down in time under

the same voltage which it has withstood for a considerable time. The maximum pressure therefore if only of brief duration should be allowed to be higher than a pressure which is continuous to cause the same breaking down strain in the dielectric. With a battery applied suddenly to a cable without condensers the whole

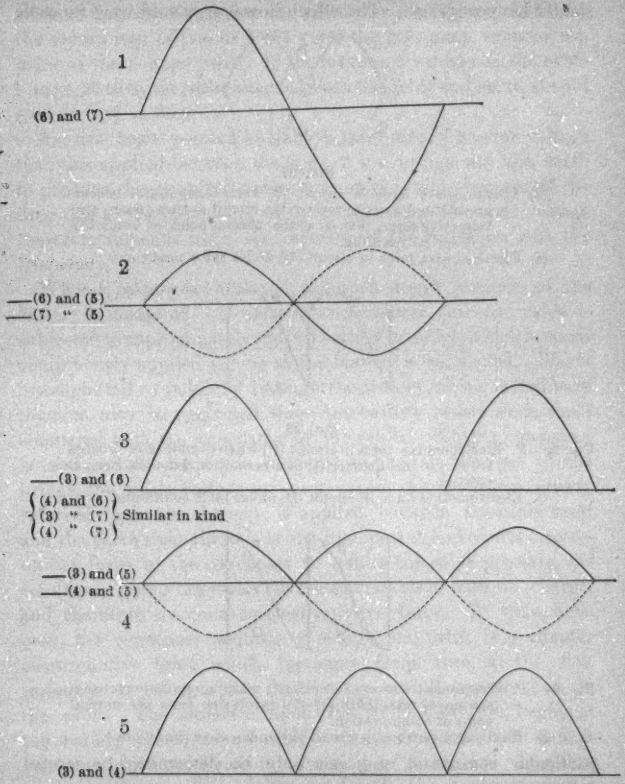


FIG. 26.—Forms of electromotive force obtained by connecting the various alternator brushes.

pressure is upon the cable during the entire length of a signal, whereas with the sine wave method the maximum voltage is applied but a single instant and cannot be applied longer if desired.

If air were the insulating material of a submarine cable it is known that the breaking strain is measured by the maximum voltage to which it is subjected, and is independent of the time during which this pressure is applied. When gutta percha or rubber are the materials used for insulation this time element should be considered. The effect, however, would vary for each

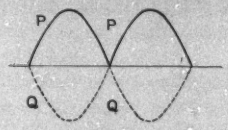


FIG. 27.

(3) Electromotive force in circuit (P) when commutator brushes are situated so as to reverse the circuit at time of zero electromotive force, that is, at the normal point of commutation for no sparking.
(4) Electromotive force in circuit (Q) under same conditions.

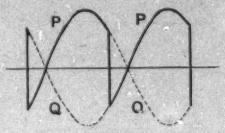


FIG. 28.

FIG. 28—P. Electromotive force in circuit (P) when commutator brushes are moved one-quarter ($\frac{1}{4}$) of a revolution from the normal position.
Q. Electromotive force in circuit (Q) under same conditions.

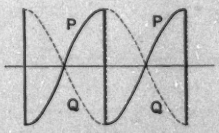


FIG. 29.

FIG. 29—P. Electromotive force in circuit (P) when commutator brushes are moved one-eighth ($\frac{1}{8}$) of a revolution from the normal point of commutation.
Q. Electromotive force in circuit (Q) under same conditions.

particular compound and can only be determined by careful tests.

Equivalent voltages are therefore considered to be employed by the two systems when the same maximum potential difference between the core of the cable and the earth is attained at some time during each signal.

The fact that condensers are employed between the trans-

mitter and the cable so modifies the pressure applied to the cable itself that the voltage and the methods of measurement are entirely different in the two systems. When a sine wave is employed, the pressure may be read directly from an electrostatic voltmeter between the end of the cable itself and the earth. Because they are sine waves the voltmeter reading multiplied by the square root of two or 1.414 gives the maximum value or top point of the voltage wave. If the maximum voltage on the cable is to be 50 then the voltmeter between the cable and earth should read $50/\sqrt{2} = 35.4$.

As has been pointed out above it requires a greater voltage than this applied between the apex of the bridge and the earth to produce the required pressure upon the cable because of the drop due to the impedance of the condenser. The apex voltage therefore depends upon the capacity of the condenser and the frequency.

When a battery is employed, the open circuit pressure of the battery is measured. If there is no condenser, then the cable is subjected to approximately the full battery pressure, which remains continuously applied as long as the battery is connected. There is a slight fall of potential through the battery, which, in ordinary practice, may be neglected, since the battery resistance is small compared with the impedance of the cable. When a condenser is used and the battery is suddenly applied to the apex of the bridge, the whole battery pressure, except the small loss already referred to in the battery, is applied between the cable itself and the earth since there is at the first instant no counter electromotive force in the condenser to reduce the cable pressure, the condenser being originally in the neutral state with no charge, and therefore no counter electromotive force. In time, however, the condenser acquires a charge, and with it a counter electromotive force which increases from zero at the first instant to a value which finally prevents all current flow in the cable. The pressure upon the cable, therefore, begins at the battery pressure and rapidly diminishes with time until it has practically vanished in a fraction of a second. In either case whether condensers are employed or not, the maximum pressure to which the cable itself is subjected is approximately equal to the battery voltage. The difference is that with condensers this pressure is momentary, while without them it is continuous. The phenomena with a sine wave and a battery wave depend entirely upon the manner in which the electro-

motive force is applied. When applied suddenly as with a battery the condenser has not had time to acquire a charge or counter electromotive force before the maximum pressure is reached. With a sine wave beginning at zero and increasing gradually to a maximum, the condenser acquires a charge before the maximum point is attained, and therefore the apex pressure must exceed the cable pressure. The rule for obtaining equivalent voltage in the two methods may then be stated by the answer to the following question: "What sine wave electromotive force steadily applied to the sending end of a cable, as measured by a properly calibrated electrostatic voltmeter inserted between the sending end of the cable and earth, produces the same maximum electromotive force in each wave as the maximum electromotive force applied to the cable by an earth connected battery, either directly as in ordinary simplex working without sending condensers; or to the apex of the bridge, and therefore through condensers, as in duplex working?"

The answer is that the virtual alternating pressure or sine wave electrostatic voltmeter reading, which is 70.7 per cent. of the full battery voltage produces the same maximum pressure in each alternation or wave as the battery. For example, a sine wave which produces an electrostatic voltmeter reading of 35.4 volts between the cable and earth is equivalent to a battery of 50 volts whether applied to the cable directly or through condensers.

Why there is a Gain in Speed Using the Sine Wave Instead of the Battery at the Same Voltage.

The received waves through a long submarine cable are approximately sine waves, whether true sine waves or even battery reversals are employed at the transmitting end. With the same maximum voltage at the transmitting end of the cable, however, the amplitude of the wave at the receiving end is greater when the sine wave is employed, which means that more energy is transmitted by the cable. This is equivalent to attaining higher speed, since with the same speed as the battery transmitter the amplitude of motion and definition is greater; but by tightening the suspensions and quickening the natural period of the recorder, the same definition and amplitude is obtained at a higher speed.

The reason why more energy is transmitted is plain. A wave such as battery reversals send to the cable may be analyzed by Fourier's theorem into a number of component simple sine waves, which consist of a fundamental wave and harmonics having

higher frequencies. Lord Kelvin's theory maintains that it is only the first or fundamental term of such a series of waves which pass through the entire length of the cable with an appreciable effect, and this theory is fully confirmed by the experiments already described as a reference to the curves in Fig. 11 will show. If, for example, the fundamental wave had a frequency of 5, the double amplitude of the recorder would be about .065 inches, which is a working value. The harmonic having double the frequency of this, viz., 10, would not have any observable effect upon the distant recorder, as this is beyond the limits of the observed curve (3), which extends to a point about a frequency of 7, where the double amplitude of the record is less than the width of the recorder line. It is therefore only the fundamental sine wave component of the battery wave which is useful in operating the receiver, and it is evident that this fundamental wave has a maximum much below the maximum point of the battery wave. Let (1) Fig. 25 represent a sine wave which has the same maximum point as the battery wave (2). The only effective portion of the battery wave, as far as the distant receiver is concerned, is the fundamental term in its analysis, which may be represented by the sine wave (3), which evidently has a maximum point considerably lower than the top of (1) or (2).

The strain upon the dielectric of the cable is approximately the same for the battery wave (2) as for the sine wave (1), which has the same maximum value, but the effectiveness of the battery wave upon the distant receiver is only equivalent to the smaller sine wave (3).

It thus appears that the many harmonics necessary to make the battery type of wave, are entirely useless in signaling, and introduce an extra charge into the cable which must be discharged between signals.

Experiments Affecting the Character of Telegraphic Cable Signals.

The following experiments were made upon the No. 3 Altantic cable of the Commercial Cable Co. at Waterville, Ireland. The object was to determine the effect upon the character of the signals produced by modifying in various ways the simple sine wave elements.

Methods of Discharging the Cable.

a. The ordinary method of battery signaling connects the cable to earth during the latter portion of each signal, which permits the discharge of the cable and separates the successive signals.

The sine wave naturally separates the successive signals and tends to discharge the cable since the electromotive force reduces to zero for each impulse while the cable is connected to earth. If the cable is not connected to earth between letters and words it is difficult to distinguish where the letter begins and ends upon the record. To furnish a path for the discharge of the cable several methods were tried. A shunt resistance was directly connected from the apex to the earth, which furnished at all times a path for the discharge of the cable. This arrangement required that the generator should maintain the terminals of this shunt at the voltage desired upon the apex. This causes a load upon the generator in addition to that required for signaling which increases more and more as the value of the shunt is decreased. In practice on the Atlantic cable it was found that the value of the shunt required to produce sufficient discharge is so small that the power required from the generator is out of proportion to the work of signaling proper.

With the large capacity of an Atlantic cable it is best to have a direct earth connection without resistance. This is ordinarily accomplished in the battery system by means of a sounder transmitter in conjunction with the automatic transmitter, which disconnects the battery and connects the cable to earth during the latter portion of each signal.

This may be accomplished by the sine wave transmitter if it is connected to the sounder transmitter in the following manner. The electromagnets of the sounder transmitter are operated by local battery power governed by the perforations in the tape which passes through the synchronous transmitter geared to the generator. In place of the signaling battery the armature of the sine wave alternator is substituted. The size of the perforations in the tape governs the relative durations of earth connection to current impulse.

The above method utilizing the regular sounder transmitter produces the required result, but it is simpler and more reliable to entirely dipense with the sounder transmitter and use the sine wave transmitter alone, which accomplishes what the present automatic and the sounder transmitter together accomplish. The method referred to is the transmitter already described employing three separate lines of holes in the transmitting tape. Thus the number of contacts is reduced from six to three, four of the six being required for the sounder transmitter. Of a large number of methods of accomplishing this result by the use of relays,

rectifiers, etc., the method employing three hole tape which entirely dispenses with any form of relay, with its continuous source of errors and delays, experience has shown to be one of the most simple and reliable.

b. In order to ascertain whether there is any advantage in making an earth connection between successive signals of a single letter a ring was mounted upon the shaft of the generator, so that the cable and earth could be connected during any portion of a semi-cycle desired. This is equivalent to changing the size of the perforations in the tape but affords an easier means of varying the earth contact. A series was taken, using the same transmitting slip and varying the degrees of earth contact from 0 to 60 degrees or one-third semi-cycle. These records were carefully compared and reported upon by the expert operators in Canso, who were purposely not informed of the changes that were being made, with the result that the best signals were reported when little or no earth was employed between successive signals.

An experiment was made to determine whether the different letters of the cable alphabet are transmitted and received with equal facility, and if not, which letters of the alphabet are most legible at the highest speed. It is understood that operators are now trained to read letters which have successive signals of the same polarity without detecting the individual signals, and indeed prefer such letters; but the following conclusive experiment was devised to determine the relative value of the so-called cross-letters of the alphabet, such as "a," "n," "k," "r," etc., having successive signals of alternate polarity, in comparison with letters like "m," "g," "h," &c., having successive signals of the same polarity. Two lists of English words were prepared, one consisting of cross letters only, such as "acre," "nearer," "center," "trace," &c., and another of other words, such as "should," "how," "plow," etc., and no information as to the object of the experiment or of the words being transmitted was communicated to Canso. The messages were then transmitted at a rate higher than they could be read, and the speed gradually reduced until the extreme limit of legibility was reached. The result of these tests was that the cross letters could be read at a considerably higher speed. This experiment was repeated several times, different words being employed, with the same results. The above is an inherent defect in the present alphabet, an ideal alphabet being one in which each letter has the same limit of legibility.

An Automatic Transmitter in which the Electromotive Force Applied to the Cable is Modified for Certain Letters Only.

Since the cross letters of the alphabet have a higher speed limit than the other letters, it seemed desirable to make the same transmitter send the latter letters with the electromotive force somewhat modified without changing the cross letters. One method of easily modifying those letters which have two or more successive sinuses of the same polarity is to change the electromotive force of the second and succeeding sinuses in magnitude only without changing its direction or sine wave shape. Plate III A shows a record made by the siphon recorder on a local circuit with the transmitter thus modified, where it is seen that the second and third dots of the letter "b," instead of being the same size as the first dot, as they ordinarily are on a local circuit, are considerably reduced. On the other hand, the letter "c," for example, and all the other cross letters, remain unaltered. In the letter "h" the last three dots are small and the first large. This transmitter being entirely automatic, the relative size of the first and successive signals of these letters is under control, even without stopping the transmitter, by an adjusting rheostat. With this transmitter a series of tests were made on the Atlantic cable, the receiving experts in Canso being uninformed as to the nature of the experiment. It was found easy to change entirely the appearance of the modified letters at the receiver, from their normal appearance with rheostat open, to a signal unrecognizable when the succeeding sinuses of the letters were practically reduced to zero by a change of the rheostat. The letter "h," for example, which normally rises from the zero line of the recorder at each successive signal, was made to remain horizontal or to descend, as desired. By this method it is possible to improve some of the letters, but others, such as "l" or "y," are apparently no better, if as good.

Another method of modifying certain letters without altering others was tried with the three-hole tape transmitter, which consisted of applying a battery instead of the armature of the sine wave alternator to the two signaling brushes. Because the holes in the perforated tape are so large that consecutive perforations on the same side cut away all the paper between the holes allowing the brush to make continuous contact through two or more consecutive perforations, the cable only receives a single impulse at the beginning of a succession of dots or dashes of the same

polarity due to the sending condensers which quickly stop the current. The cable, however, receives a sufficient charge to cause the receiver to give the letters so affected their normal appearance. Evidently the "cross letters" are not affected thereby, being the same as with the ordinary battery transmitter. An example of a record received by this method is seen in Plate III, B.

The results thus far obtained upon this cable indicate that, everything considered, the simple sine wave signals unaltered in any way give, on the whole, the most readable signals throughout the alphabet.

Transformers.

It is a natural step in the development and use of the sine wave of electromotive force for cable signaling to employ ordinary alternating current apparatus, among which the closed circuit alternating current transformer occupies a conspicuous place. It was not until after a transformer had been obtained, with a view of using it in transmitting messages, that the good results obtained with transformers in England by Mr. Dearlove came to our notice. The transformer used was a commercial one, specially wound with five separate coils, designed to operate on 1,000, 500, 500, 50, and 50 volts respectively.

In using the transformer for signaling, the alternator is connected directly to the primary, while the secondary, which may be considered as the source of the transmitting electromotive force, is connected directly between the apex of the bridge and earth. This gives a permanent low resistance connection between the cable and the earth and dispenses with any form of earthing device. The general effect of the transformer is to give a natural curb to the impulses transmitted through it, since a single positive sinus in the primary circuit produces both a negative and a positive sinus in the secondary circuit whose values depend upon the inductance and the frequency. Plate III C shows a record received in Canso, using a transformer for transmitting at New York. It is seen that the letters like "h," which usually rise from the zero line, in this case descend towards it. With an adjustable inductance, the general characteristics of the received record can be changed materially and at will, so that the "s" or "h" may either rise from the zero line, descend toward it, or remain approximately horizontal.

To determine whether the magnitude of the current received through the Atlantic cable is sufficient to operate a receiving transformer, messages were sent from Canso and received in

Waterville. The regular duplex arrangement was retained, and the primary of the transformer inserted where the siphon recorder ordinarily is, the condenser in series with the recorder being removed. The particular winding of the transformer then available was not suitable for obtaining the best results over the cable, but records were obtained which could be read, and the above is cited as showing that there need be no hesitation in employing transformers as far as the magnitude of the currents is concerned.

The substitution of comparatively inexpensive transformers for the condensers now required in duplex working would be an advantage from many standpoints. In the future development of cable telegraphy, both the transformer and the condenser will probably play an important part.

Conclusion.

The real test of cable apparatus is its efficiency for continuous work in the hands of average cable operators, and in the development of the details of the transmitter its use in actual traffic on the Atlantic cable for several days at a time has been of great value.

One of the radical features of the transmitter shown is the employment of small steel brushes, making contact through the perforations in the tape with a platinum cylinder having a corrugated surface. The present automatic transmitters of the Wheatstone type, make the electrical contacts at a point away from the transmitting tape by means of a system of levers. In using the alternating current always interrupted at the zero point there is not the same objection to the use of brushes due to sparking which is the case when a direct current is suddenly broken at a high voltage. Any system of levers is impossible for very high speed telegraphy, and the elements of a transmitter could hardly be more simple and direct acting then making contact through the tape with some form of brushes. It is evident that either form of transmitter may be used with the cable alternator, but the brush form as now perfected is preferred.

The sine wave transmitter removes the necessity of any form of battery power for a cable station. The same armature furnishes the power for hand transmission as well as automatic, and the same convenience in switching from one to the other is maintained as at present. The present tendency in telegraphic engineering is to remove all forms of primary batteries as a source of power, and the sine wave alternator combines this advantage with the most efficient form of wave for signaling.

As evidence of the character of the signals produced by the sine wave method as compared with the battery method, a few examples have been selected from signals received at Waterville, Ireland, transmitted from Canso, Nova Scotia, and from signals received in Canso transmitted from New York, which are appended herewith in Plate I.

Plate II shows three examples of battery signals received in Ireland transmitted from Nova Scotia.

Plate IV shows some comparative sine wave and battery signals showing the same message transmitted from New York to Nova Scotia.

Plate V. shows a sine wave record at the receiving end and at the transmitting end of the C. I. cable.

In closing this paper it is desired to record our appreciation of the very unusual facilities placed at our disposal by the Commercial Cable Co. of New York, extending over a period of nearly two years, and the valuable assistance rendered by their engineers.

APPENDIX.

Some Electromotive Forces Obtainable with the Transmitter.

In the previous explanation of the transmitter the brushes were so placed that the signals were transmitted in the normal way. The effects of shifting both the commutator and transmitter brushes furnish a variety of electromotive forces. Referring again to Fig. 3, two additional collector rings C and D (not shown in the diagram) are placed upon each transmitter so that the simple alternating current may be obtained directly from the whole armature. The rings are connected one to each terminal of the armature winding C, being joined to segment (1), and D to (2) commutator A. There are then upon the shaft the divided ring A and three collector rings, B, C and D. Upon A bear two diametrically opposite brushes (3) and (4), and upon B, C and D, three brushes (5), (6) and (7) respectively. Figure 26 shows a series of electromotive forces obtained by joining any two of the five brushes (3), (4), (5), (6) and (7). By connecting brushes (6) and (7) a simple alternating electromotive force from the whole armature is obtained. By connecting (6) and (5), or (7) and (5) simple alternating electromotive forces are obtained from the half armature, exactly opposite in phase. When the commutator brushes (3) and (4) are set in the neutral position, curves 4 show the electromotive forces obtained by joining (3) and (5) and (4)

and (5) which are rectified electromotive forces of the half armature. This is the combination used for cable signaling.

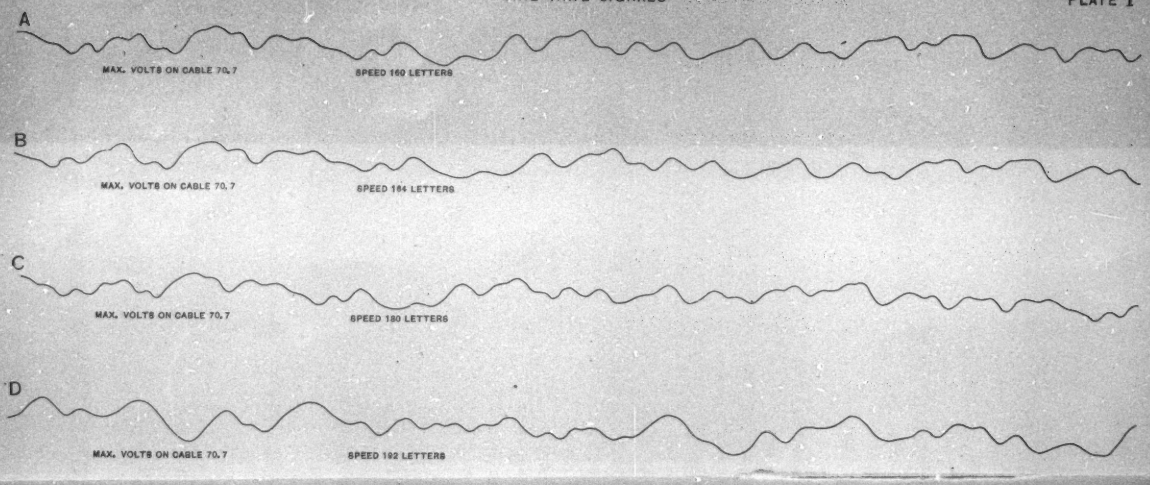
Figs. 27, 28 and 29 represent the electromotive forces obtained at the transmitter brushes P and Q for three different positions of the commutator brushes (3) and (4), the connections being as shown in Fig. 3. The heavy line represents the electromotive force at brush P and the dotted line at brush Q. Fig. 27 shows the electromotive force when brushes (3) and (4) are in the normal or zero position of commutation, Fig. 28 when they are revolved one-eighth, and Fig. 29 a quarter of a revolution from the neutral position.

Three series of curves are shown in Figs. 30, 31 and 32, each set corresponding to the same position of dynamo brushes (3) and (4), as the electromotive force curves Figs. 27, 28 and 29 respectively. These series show the resulting electromotive forces obtained when the transmitting tape is used, having simple alternating perforations, and each begins and ends with the simple harmonic electromotive force, the succeeding curves representing the effect of shifting the transmitter brushes P and Q one-sixteenth of a cycle longitudinally along the tape by means of the micrometer screw. The actual distance which the brushes move corresponding to the consecutive curves is 1/80 of an inch. The heavy portions of the curves represent that which is transmitted through perforations in one side of the tape, and the dotted portions through the opposite side. Three series of curves were obtained upon the siphon recorder with the sine wave transmitter on a local circuit, and are exhibited in Figs. 33, 34 and 35. With sudden changes in the electromotive force the siphon moves across the tape without making a mark. The series exhibits a close similarity to the theoretical curves, Figs. 30, 31 and 32.

(Reproduced from Siphon Records, natural size.)

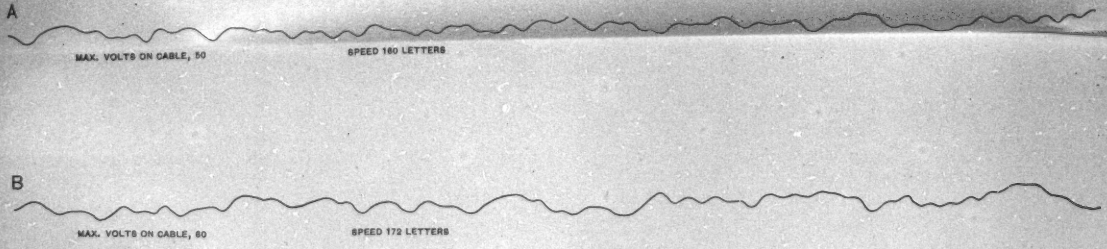
SINE WAVE SIGNALS

PLATE I



ORDINARY BATTERY SIGNALS.

PLATE II



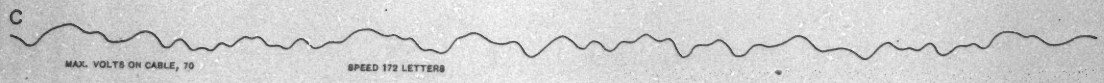
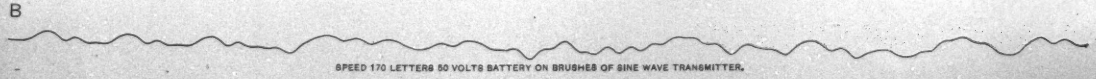
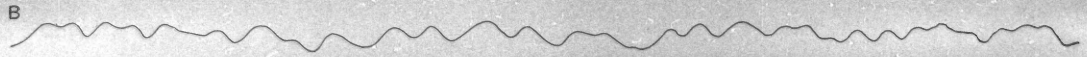


PLATE III

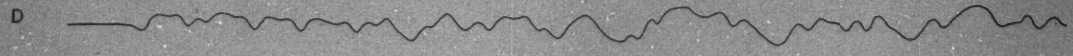


Through transmitting transformer.

PLATE IV



A. The Cuttriss transmitter. Battery 36 volts max. on cable. 158 letters per minute. n — 4.9.
B. Sine Wave transmitter, 30.8 volts max. on cable. 157 letters per minute. n — 4.86.



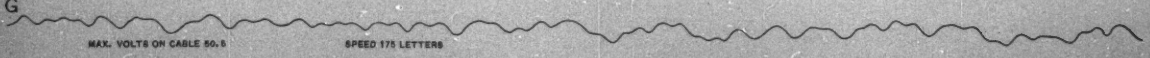
C. Cuttriss Transmitter. 180 letters per minute. n — 5.61, max. 36 volts on cable.
D. Sine Wave transmitter. 182 letters per minute. n — 5.66. maximum 33 volts on cable.

MAX. VOLTS ON CABLE 70.7 SPEED 198 LETTERS

F

MAX. VOLTS ON CABLE 27.3 SPEED 153 LETTERS

G

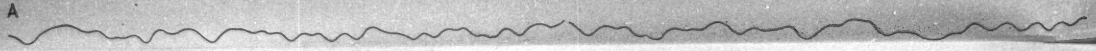


MAX. VOLTS ON CABLE 50.6 SPEED 175 LETTERS

ORDINARY BATTERY SIGNALS.

PLATE II

A



MAX. VOLTS ON CABLE, 50 SPEED 160 LETTERS

B

MAX. VOLTS ON CABLE, 60 SPEED 172 LETTERS

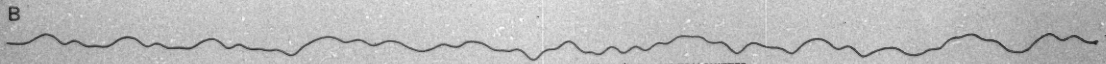
C

MAX. VOLTS ON CABLE, 70 SPEED 172 LETTERS

PLATE III

A

B



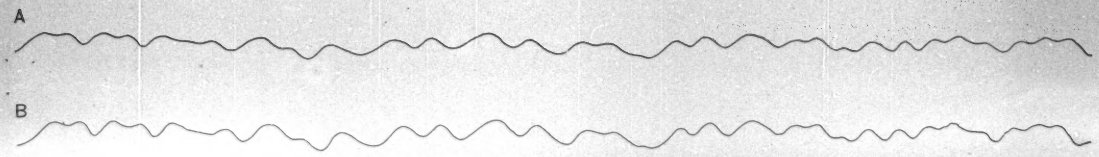
SPEED 170 LETTERS 50 VOLTS BATTERY ON BRUSHES OF SINE WAVE TRANSMITTER.

C

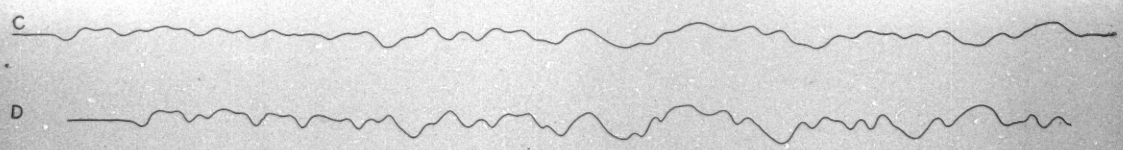
Through transmitting transformer.

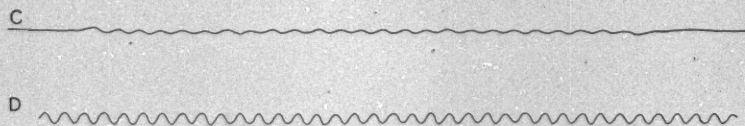
Through transmitting transformer.

PLATE IV



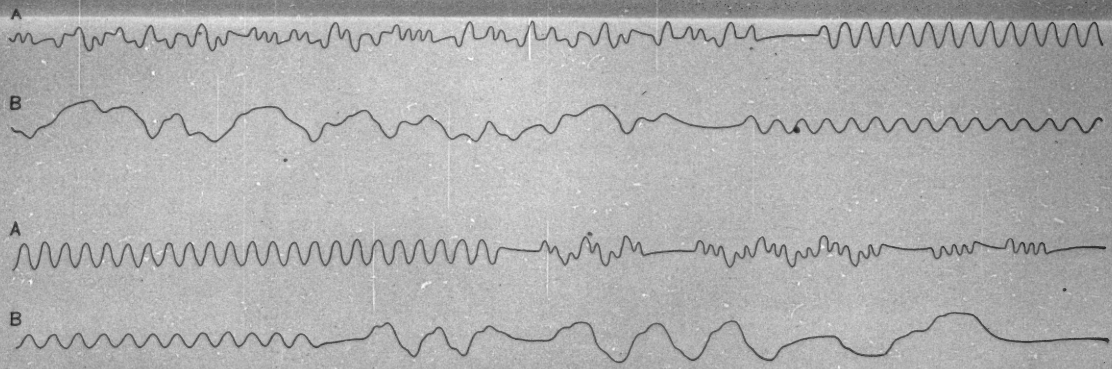
A. The Cuttriss transmitter. Battery 36 volts max. on cable. 158 letters per minute. n — 4.9.
B. Sine Wave transmitter, 30.8 volts max. on cable. 157 letters per minute. n — 4.86.





C. Cuttriss Transmitter. 180 letters per minute. n — 5.61, max. 36 volts on cable.
D. Sine Wave transmitter. 182 letters per minute. n — 5.66. maximum 33 volts on cable.

PLATE V



A — TRANSMITTING END
B — RECEIVING END

n — 8½
SPEED — 106 LETTERS PER MIN.

PAGE GROUP 300

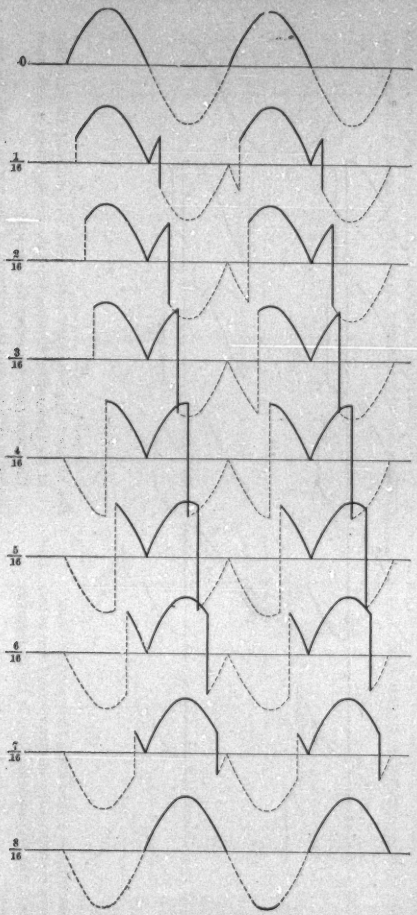


FIG. 30.

The series of curves shows the electromotive force acting in circuit (5), that is, in the transmission line, as the transmitter brushes are adjusted.

The numbers opposite each figure indicate the phase of displacement of the transmitter brushes from the position they occupy when the commutator reverses the circuits.

The commutator brushes are in the normal position.

The heavy line, as in previous diagrams, denotes the part of the curves which is transmitted through brush circuit (8), and the dotted line through brush (4).

FIG. 31.—Commutator brushes ¼ revolution from neutral point.
The series of nine curves represents the electromotive force acting in circuit (5), that is, the transmission line, as the transmitter brushes are adjusted.
The commutator brushes are fixed at one-eighth of a revolution from the neutral point.

The numbers opposite each curve give the phase of displacement of the transmitter brushes from the position they occupy when the commutator reverses the circuits.
The heavy line denotes the portions of the curves where the electromotive force is transmitted through brush circuit (3) and the dotted line through circuit (4).

FIG. 32.—Commutator brushes ¼ revolution from neutral point.
The series of nine curves represents the electromotive force acting in circuit (5), that is, the transmission line, as the transmitter brushes are adjusted.
The commutator brushes are fixed at one-quarter of a revolution from neutral point.
The numbers opposite each curve give the phase of displacement of the transmitter brushes from the position they occupy when the commutator reverses the circuits.
The heavy line denotes the portions of the curves where the electromotive force is transmitted through one-brush circuit (3), and the dotted line through circuit (4).

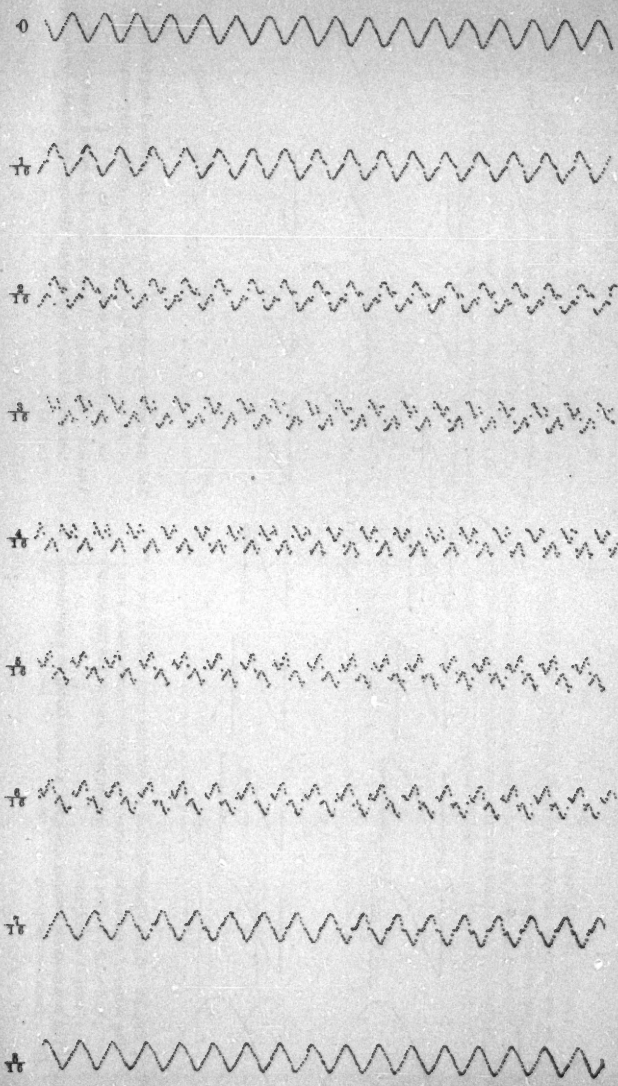


FIG. 33.—Zero Phase. Siphon record corresponding to Fig. 30.

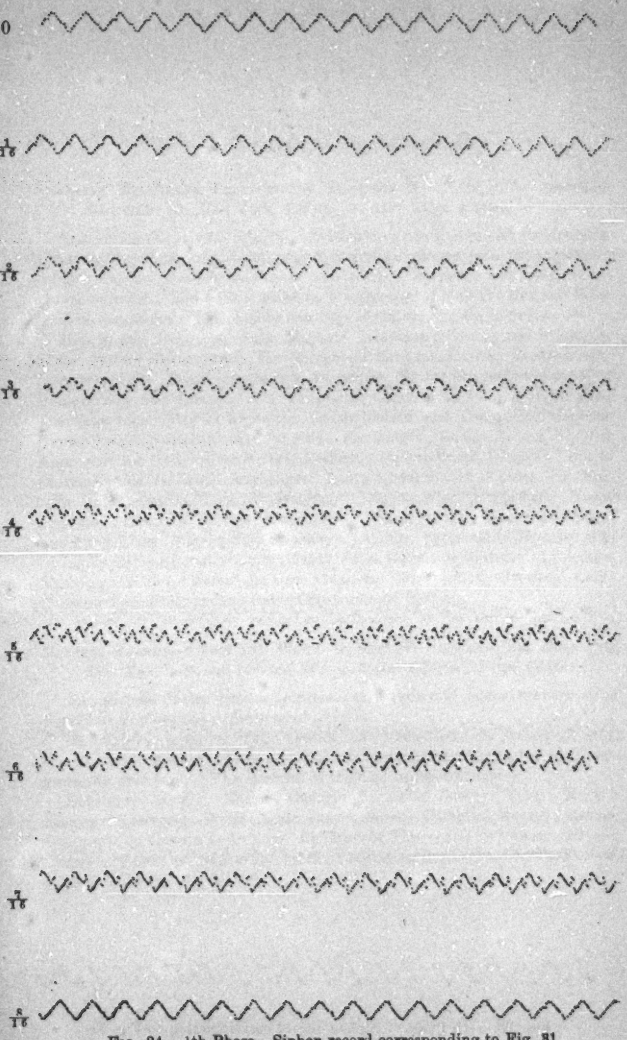


FIG. 34.—$\frac{1}{16}$th Phase. Siphon record corresponding to Fig. 31.

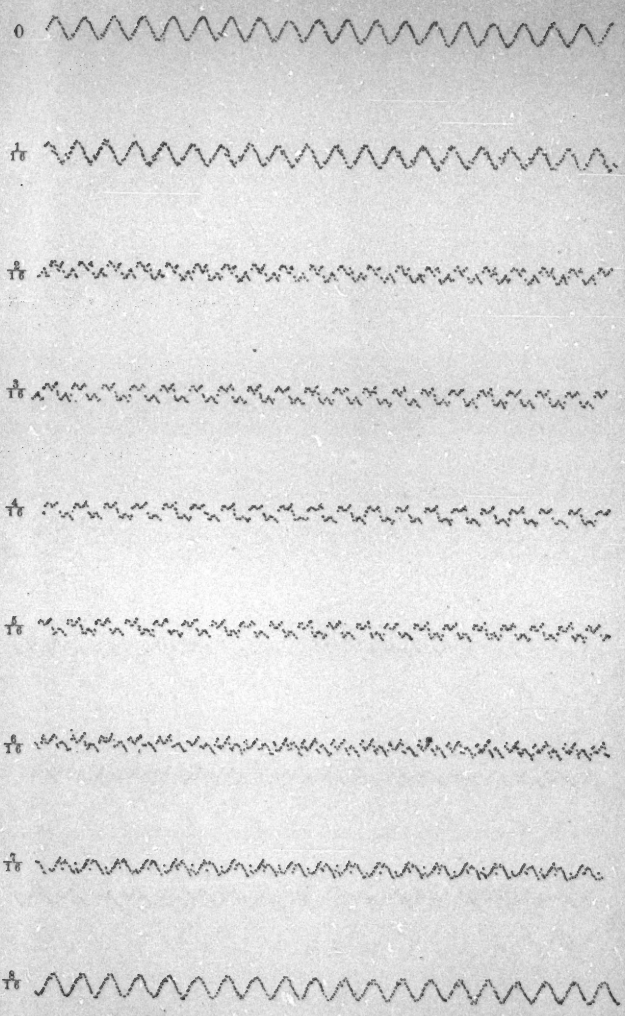


FIG. 35.—$\frac{1}{4}$th Phase. Siphon record corresponding to Fig. 32.

Books Received by the Institute.

American Telephone Practice, by Kempster B. Miller. *The American Electrician Co.*, New York, 458 pp. 357 cuts, 6½in. x 9½in.

Embodying the general principles of telephony, the design and construction of commercial apparatus, the circuits connecting such apparatus into operative systems, and the methods used in the construction, operation and maintenance of such systems. The work is based on the practice of both the Bell and independent companies. The chapter headings of the volume are as follows:—

History and Principles of the Magneto Telephone; History and Principles of the Battery Transmitter; The Telephone Receiver; Carbon Transmitters; Induction Coils; Batteries; Calling Apparatus; The Automatic Shunt; The Hook-Switch and Circuits of a Telephone; Commercial Calling Apparatus; The Telephone Relay or Repeater; Self-Induction and Capacity; Telephone Lines; Simple Switch-Boards for small Exchanges; Listening and Ringing Apparatus for Switch-Boards; Self-Restoring Switch-Board Drops; Complete Switch-Boards for Small Exchanges; Lamp-Signal Switch-Boards; The Multiple Switch-Board; Transfer Systems; Common Battery Systems; House Systems; Protective Devices; Distributing Boards; Party Lines; Non-Selective Party Lines; Step-by-Step Selective Signaling; Party Lines Selective Signaling by Strength and Polarity; Party Lines Harmonic Systems of Selective Signaling; Wire for Telephone Use; Pole-Line Construction; Overhead Cable Construction; Underground Cable Construction; Testing.

Matter, Energy, Force and Work, by Silas W. Holman. The Macmillan Co., New York and London, 257 pp. 5½in. x 7½in. Price, $2.00.

The purpose of this book is to present in a plain and logical manner some fundamental ideas and definitions of physics.

Through the progress of the application of science to the industrial arts, correct views of energy, force and work are essential in all branches of the engineering profession. The contents of the book are as follows:—

Substance, Matter; Motion; Energy; Forms of Energy; Force; Kinetic Energy; Kinergety; Force Measurement; Work; Potential Energy; Matter; Comments on Certain Definitions; Function of Theory and Hypothesis; Kinetic Theory of Gases; Le Sage's Theory of Gravitation; The Vortex-Atom Theory; Nature of Energy and Matter.

APPLICATIONS FOR ASSOCIATE MEMBERSHIP.

Applications have been received from the following candidates for Associate Membership, which will be acted upon by Council at its meeting, July 25, 1900.

1698. Lewis A. Howland, Montreal, P. Q.
1699. Emil Dysterud, Monterey, Mex.
1700. Louis James Benard Wall, Perth, West Australia.
1701. A. W. McLimont, Guanajuato, Mex.
1702. Carl B. Auel, Pittsburg, Pa.
1703. E. W. Ackland, Perth, West Australia.

Any member objecting to the election of any of the above candidates should notify the Secretary to that effect prior to July 25, 1900.

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